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U.S. Bureau of Mines

RESEARCH 88

a summary
of significant results
in mineral technology
and economics

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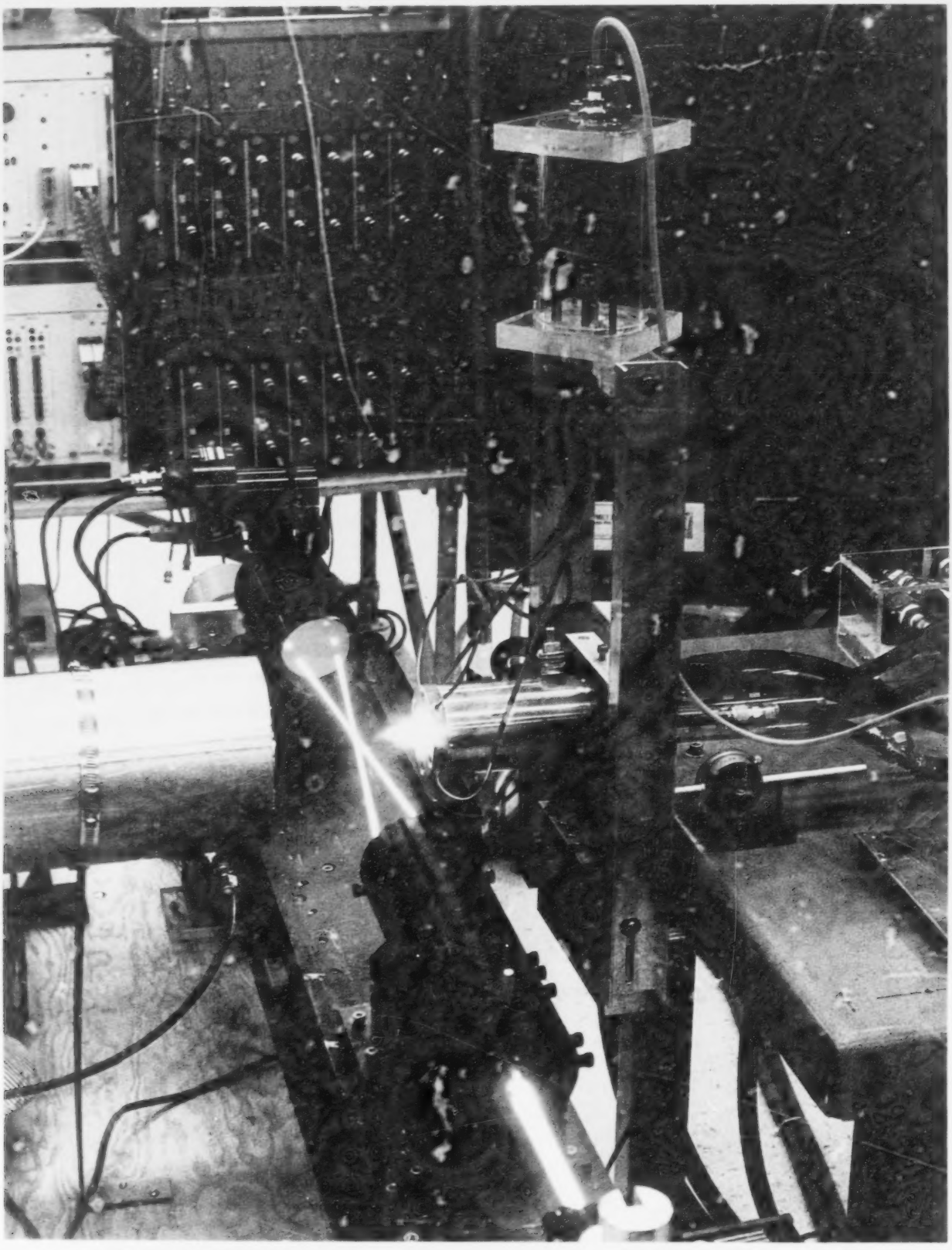

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Facing page:

Laser and plasma arc technologies are used in this experimental mineral processing method.

Cover photograph:

Mineral exploration. Although the United States is richly endowed with natural resources, economic mineral ore bodies are increasingly difficult to locate. Exploration is essential for the future health of the minerals industry and the security of domestic mineral supplies.

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Minerals and the things produced from them underlie every enterprise of modern society.
Photos above and on page iv courtesy of The National Stone Association.

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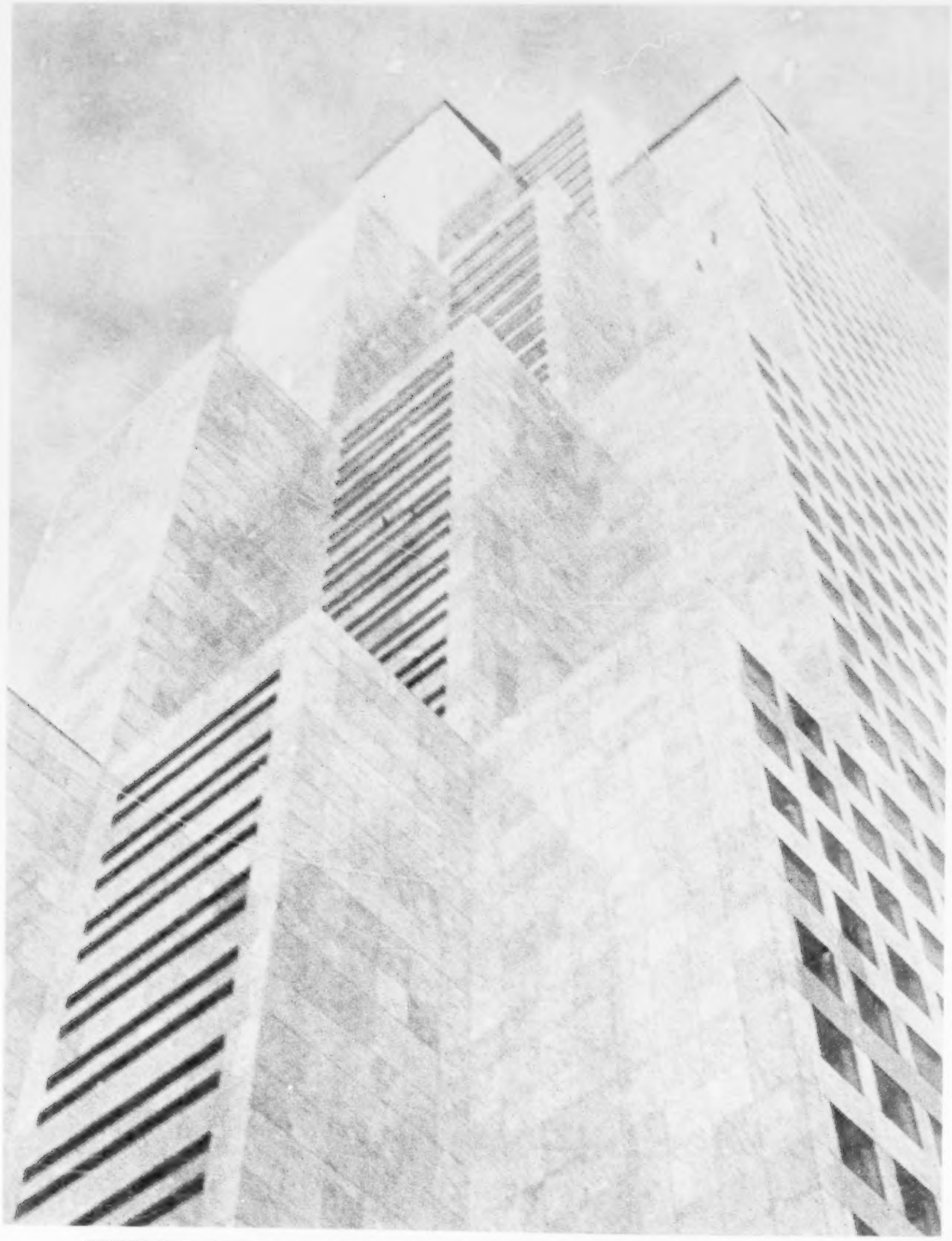


Introduction

The wealth of a nation may be measured in many ways, but one of the most important is its natural resources, particularly its minerals. Minerals create the wealth upon which economic prosperity and defense preparedness rest. Managing mineral resources for the benefit of all Americans continues to be an important national goal.

In its 78-year history the U.S. Bureau of Mines has established itself as the world's premier mineral information and research agency. Its authoritative, comprehensive data and pioneering research have contributed significantly to a strong U.S. mineral position in the world.

If the United States is to maintain its world leadership, its mineral industry must be competitive in global markets. For it to do that, we must find innovative ways to explore for minerals, to mine them, to process them, to make them into useful products, and to handle the wastes the industry generates. Innovative ways must be found to translate advanced technologies from other fields into new mining and processing systems and to improve the health and safety of American workers and the nation's environmental quality. A balance must be reached that will allow us to reach both of two worthy but sometimes competing goals: The development of our natural resources and the protection and maintenance of a quality environment.

The Bureau has gone through considerable recent changes, emerging as a more streamlined organization, with new program initiatives and with a more active involvement in issues facing the country and its mining industry. These changes have been positive and have strengthened the role and effectiveness of the Bureau.

In 1988, regulatory analysis, inventorying Federal lands, strengthening the competitive position of the United States, and the monitoring of mineral requirements for new and advanced materials continued as high priorities of the information and analysis program.

The Bureau's studies on platinum and rhodium were used extensively in the congressional debate on South African sanctions. Studies on acid rain and mine waste provided a much needed factual base for many pending policy decisions.

Nineteen eighty-eight also saw the opening of the joint BOM-USGS Minerals Information Office in the Main Interior Building. The office serves as a clearinghouse for the resource data and information of these two sister agencies and symbolizes the heightened cooperative work they are doing.

The research program continues to focus more resources into advanced technologies, processes, and materials. The environmental technology program has made much progress toward developing cost-effective technologies to prevent, mitigate, and clean water and soil contamination. Biotechnologies are an increasingly important component of our program as they show great promise for effective, low-cost contamination treatment.

Bureau studies show that new, automated separation technologies could save millions of dollars in the mineral extraction sector. Good progress continues to be made in the area of new mining systems that offer real-time automated control of equipment. In situ leach mining is another innovative field promising more economic, environmentally acceptable methods to access some mineral deposits.

There is no doubt about the importance of minerals to our way of life and the Bureau's critical work in helping to ensure their availability. We face exciting challenges as we strengthen the Nation's mineral base for the 21st century. How well that task is addressed will in no small measure determine America's ability to remain free, strong, and prosperous. The U.S. Bureau of Mines remains committed to excellence, innovation, and cooperation in pursuit of the national mineral policy "to foster and encourage . . . a sound and stable domestic mining, minerals, metal, and mineral reclamation industry . . . ."

TS Ary
Director

Innovative Mining Methods

During the 1980's, the U.S. minerals industry has found it increasingly difficult to compete with foreign mining companies in world markets. In order to survive, U.S. companies must be able to sell mineral products at the same price as do foreign companies and still make a profit. Low ore grades, high labor rates, strict regulatory constraints, greater concern for miner health and safety, and more costly environmental safeguards all handicap U.S. mines. To meet domestic mineral needs, the U.S. mining industry requires completely new technology to overcome these handicaps.

The U.S. Bureau of Mines is committed to the quest for technology that will help the minerals industry develop the necessary new mining methods. In the mining or extraction arena, research in bold new methods of mining that minimize worker exposure to hazardous underground conditions, profoundly alter interactions between mines and their environments, and reduce waste in mining have moved to the forefront. By nature, these new methods greatly reduce the dependence on extracting ore by drilling and blasting.

One of these new methods is in situ leach mining. It uses weak chemicals to dissolve valuable minerals in the ground without extensive excavations. The solutions containing the dissolved metals are then pumped from the ground to a plant for metal recovery. By eliminating the ore extraction and crushing steps, in situ leach mining reduces labor and energy costs. It also provides a mine site that is easily restored to its original condition by capping wells and dismantling the processing plant.

Research in 1988 focused on developing the ability to relate leaching solutions to site characteristics, to monitor solution movements through the ground, and to predict solution movements. A generic design manual was prepared for in situ leach mining of copper deposits. This year also marked the beginning of a major cooperative research effort with a copper mining company to study engineering factors of in situ leaching for copper at a specific deposit in Arizona.

A variation of in situ leach mining, called stope mining, allows mining companies to leach low-grade ore in underground chambers. These chambers are either specially prepared rooms formed in the host rock, or they may be rooms left from prior mining activities. By leaching the rock underground, miners save most of the costs of hauling and crushing the ore. Only a fourth of the ore normally moved would need to be moved to the surface to allow room for the stope leaching operations underground. This research concentrated on identifying thrusts that would enable mining companies to adopt technology for critical and precious metals that had previously emphasized copper and uranium recovery.

Another innovative method researched by the Bureau featured excavating ore from moderately deep deposits by powerful water jets. The mining device is lowered down a hole drilled vertically into the ground. The high-pressure water jet then erodes a cavity into the ore body, and the loosened material is pumped to the surface by slurry pumps. Upon treatment of the ore pumped to the surface, the waste rock can be returned underground by pumping it back into the same holes. Research in 1988 concentrated on developing technology that will enable the method to be used in small-diameter (1- to 2-inch) boreholes to broaden the range of possible applications.

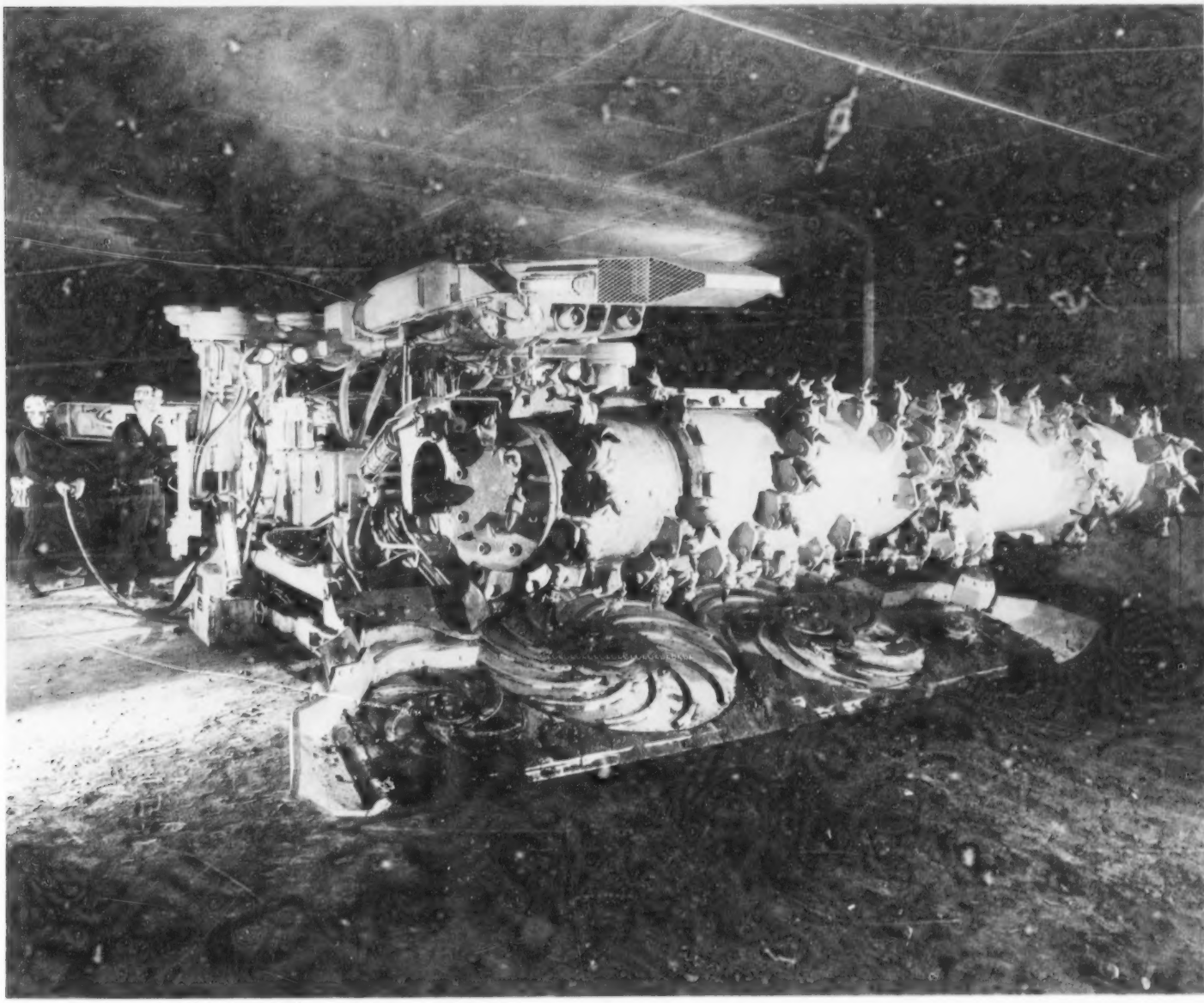
A new underground coal mining system concept will extract coal from the face, secure the roof, ventilate the coal face, move coal from the face to the section belt, and then move the section belt to keep pace with the advancing coal face; all with greater speed, increased efficiency, and enhanced safety. This new mining system is projected to increase productivity in room-and-pillar operations by 30% and eliminate accidents associated with shuttle cars and manual belt moves.

The coal will be extracted with the automated extraction system-II (AES-II), a semiautomatic prototype miner-bolter. The AES-II, which has a programmable cutting cycle, cuts a 15-foot entry in coal seams ranging from 7 to 10 feet in height, secures the roof with four onboard bolters spaced at 4-foot centers, contains an auxiliary ventilation and dust suppression system, and provides maximum operator protection.

The coal coming off the AES-II conveyor will be transported to the section belt on the automated bridge conveyor train (ABCT), a series of mobile bridge carriers and bridge conveyors equipped with an automatic guidance system. With only one operator, an ABCT up to 500 feet long can track precisely along a guidance cable laid down by the inby carrier employing a microprocessor-controlled guidance system. As the train travels, each successive carrier centers itself on the cable through the use of cable sensors and an onboard computer. The cable can be laid down and retrieved automatically by the lead vehicle as it follows behind the AES-II.

When the coal face is advanced up to the maximum length of the ABCT, the conveyor belt

service machine (CBSM) will be used to advance the section belt. The CBSM is a self-contained battery-powered vehicle capable of handling, storing, and transporting conveyor belting, wire rope, and associated structures for sectional conveyor belts. The machine has a drawbar pull of 16,000 pounds with an estimated weight of 32,000 pounds for the fully loaded machine, assuming a 50% grade ability factor. The machine can tram in either direction from creep up to 5 mph. It is capable of a 120-foot belt move distance; it can operate in a minimum seam height of 48 inches. The machine belt winder will accommodate belts up to 0.5 inch thick by 42 inches wide and provides adequate belt storage capacity for safe and convenient transportation. It has been estimated from surface time study trials that the time required to connect a belt to the belt winder reel and reel the belt onto the reel is 3.75 minutes.



A semiautomatic prototype miner-bolter is part of a new underground mining system designed to extract coal with greater speed, increased efficiency, and enhanced safety.

Materials Research and the National Economy

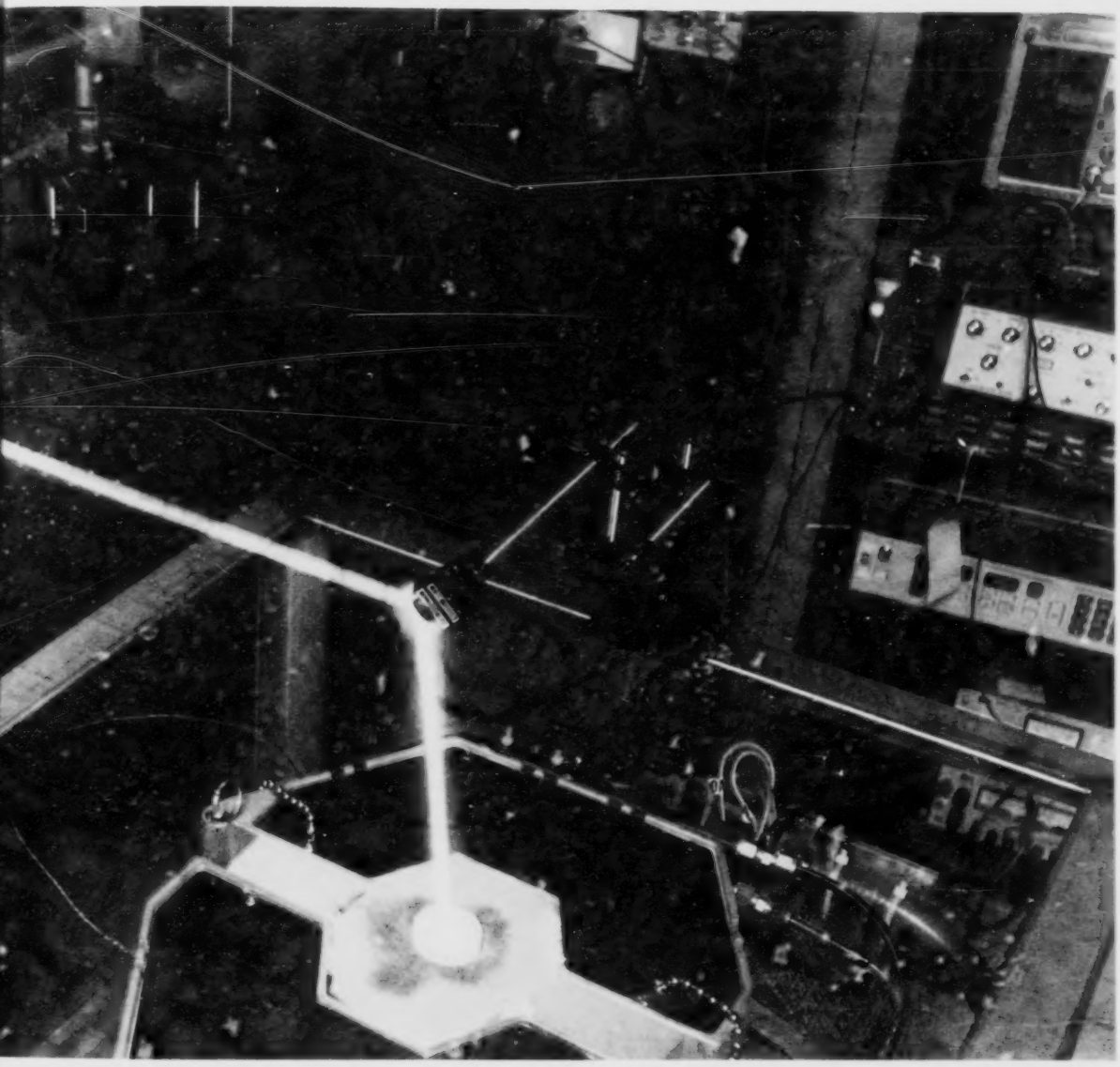
Materials research is considered by many to be the most important area of research. For without improved materials, the advanced technologies needed to keep our Nation globally competitive will not be forthcoming. Improved materials are needed by our mining and mineral processing industries not only to improve viability and productivity, but to enhance the development of new technologies that will enable this Nation to make better use of its domestic resources. Improved materials are needed, as well, to maintain our world leadership position in such diverse areas as electronics, optics, computers, aircraft, ships, automobiles, biotechnologies, weapons systems, manufacturing equipment, etc. The sought-after leapfrog improvements will only evolve through dramatic, innovative advances in the materials used to make the products.

The objectives of the U.S. Bureau of Mines materials research program are essentially to increase conservation of our resources by developing improved materials that last longer, to more effectively utilize our domestic resources in producing advanced materials, and to reduce our dependency on imported raw materials. These unique objectives differ considerably from those of other materials-concerned agencies.

The Bureau has a long history in materials research dating back to pre-World War I days, and can cite many materials research accomplishments that have had significant impacts on both national economy and security positions. These range from the generation of basic thermodynamic and corrosion data to processes for producing synthetic mica, titanium metal, nuclear zirconium, chemical-vapor deposited tungsten coatings, high-purity metals, steel-furnace refractories, aluminum solders, sulfur polymer cements, hard surfacing, and recycled wastes.

Through the years, the Bureau's principal materials concerns have been directed to the structural, wear, corrosion, and high-temperature areas and its future program will build on these areas of expertise. Its mission-oriented, generic approach is divided into three materials categories: synthesis, processing, and characterization. Generally, synthesis includes the formulation of powders, fibers, and polymers by chemical techniques; processing includes conversion and densification of basic ingredients into structural materials; and characterization includes studies of materials behavior including stability, wear, and corrosion.

The Bureau's materials research program includes a number of innovative approaches that offer the likelihood of significant achievements. In its sulfur concrete research, new techniques for reducing undesirable shrinkage opens additional opportunities for new applications. Discussions have been opened with the National Research Council's Strategic Highway Research Program for use of the concrete in bridge construction and with the Army Corps of Engineers for use of the concrete in cold environment construction. In its ceramics research, novel techniques to produce strengthened ceramics through fine particle technology and microstructural con-



Beams of laser light are used to set up ultrasonic vibrations in an advanced ceramic sample under high-temperature conditions. The distortion of these ultrasonic waves caused by the ceramic microstructure is observed. In this way, microstructural changes can be measured with nonphysical contact and without damaging the ceramic sample. This information helps Bureau scientists determine how to make ceramics with properties that would allow the ceramics to be substituted for materials containing strategic and critical elements.

trol offers promise for use of ceramic material as a substitute for high-alloy steels. Research is continuing on the behavior of refractories in metal-melting furnaces in cooperation with industry. In the metals field, new low-chromium alloys have been developed in order to reduce import dependency, and cooperative research has been started with the National Institute of Standards and Technology to explore use of these alloys in cryogenic environments for superconductivity applications. In the hard-facing area, significant progress has been made in cooperation with the U.S. Army to evaluate Bureau-developed ceramic-faced alloy castings for ballistic armor.

Mine Fire Prevention, Detection, and Control

Underground mine fires are a serious threat to life, property, and mineral resources. If they are not detected and brought under control in their early stage, portions of a mine, or the entire mine, may be sealed for long periods. The escaping miners may have to travel long distance, often on foot through smoke-filled tunnels.

Between 1983 and 1987 the Mine Safety and Health Administration (MSHA) investigated 71 major coal mine fires that had resulted in 29 fatalities, numerous injuries, the abandonment of several mines, and financial losses totaling hundreds of millions of dollars. The major ignition sources of the mine fires were electrical faults, frictional heating, spontaneous combustion, and welding or cutting operations. The combustibles involved included the coal itself, insulation, conveyor belting, timbers, oil, and grease.

Although the U.S. Bureau of Mines fire research has helped to significantly reduce the number of fires in U.S. mines, additional work is urgently needed. To reduce mine fires to an absolute minimum, Bureau scientists are engaged in several areas of research to improve mine fire prevention, detection, and control.

In a full-scale aboveground fire gallery, constructed to investigate the flammability of mine materials under realistic test conditions, the effect of airflow on conveyor belt fires is being investigated. Several types of belting approved as fire resistant, and widely used in underground coal mines, were nonetheless found to burn rapidly at certain airflow rates, producing hazardous quantities of toxic combustion products. A laboratory-scale, ventilated tunnel fire test for belting is being developed that gives similar results as the full-scale gallery. This laboratory-scale test passes or fails a belt based on the extent of fire damage to a 5-foot-long sample. This improved test is expected to replace, or reinforce, the current Federal flammability test for fire-resistant conveyor belting. The Bureau is working closely with MSHA and conveyor belt manufacturers in the evaluation of the new test.

Improved methods to control and extinguish mine fires are being examined in experiments to develop a standard procedure for reliably assessing the effectiveness of coal fire extinguishants. Using a reproducible coalbed fire, the quantity of agent required to extinguish the fire is measured and compared with water extinguishment. The best extinguishants identified will then be evaluated on larger coal fires, using various application techniques.

The Bureau is also investigating the ability of mine stoppings to prevent the spread of flame and smoke during a mine fire. It is crucial that stoppings which separate mine airways withstand a fire for enough time to prevent contamination of escape routes by toxic fire products. In full-scale fire endurance tests of concrete block and galvanized steel panel stoppings in the Bruceton (PA) Experimental Mine, the stoppings were subjected to a 1-hour simulated mine fire. Stopping surface temperatures were measured and the heat energy conducted through the stoppings was determined. All test stoppings prevented the passage of smoke and fire gases. The unexposed surface of the steel stopping was much hotter than that of the concrete block stopping, but radiation from the hot metal surface was insufficient to ignite combustible materials placed near the stopping.

In work with the Colorado Mining Association, the Bureau is investigating fire hazards of oil shale and the best approach to combat oil shale fires. The minimum hot surface ignition temperatures of various oil shale dust layers have been measured. To prevent such layers from smoldering and glowing combustion, it was recommended that surface temperatures, such as found on diesel equipment, should be lower than the previously determined ignition temperatures. Additional work was performed in which large (100-ton) oil shale rubble fires were fought with water and foam and optimal strategies to combat oil shale mine fires were developed.

The spontaneous combustion potential of coals and means to suppress or prevent spontaneous-combustion mine fires are being studied. Laboratory-scale adiabatic heating experiments and closed vessel adsorption tests measure the self-heating tendencies of coals and identify the variables that contribute to the self-heating process. An empirical expression has been developed that relates the minimum self-heating temperature of a bituminous coal to its dry, ash-free oxygen content, which is readily measured by standard coal analysis. Additives to suppress the self-heating process are also being evaluated; rock dust and sodium chloride are effective inhibitors.

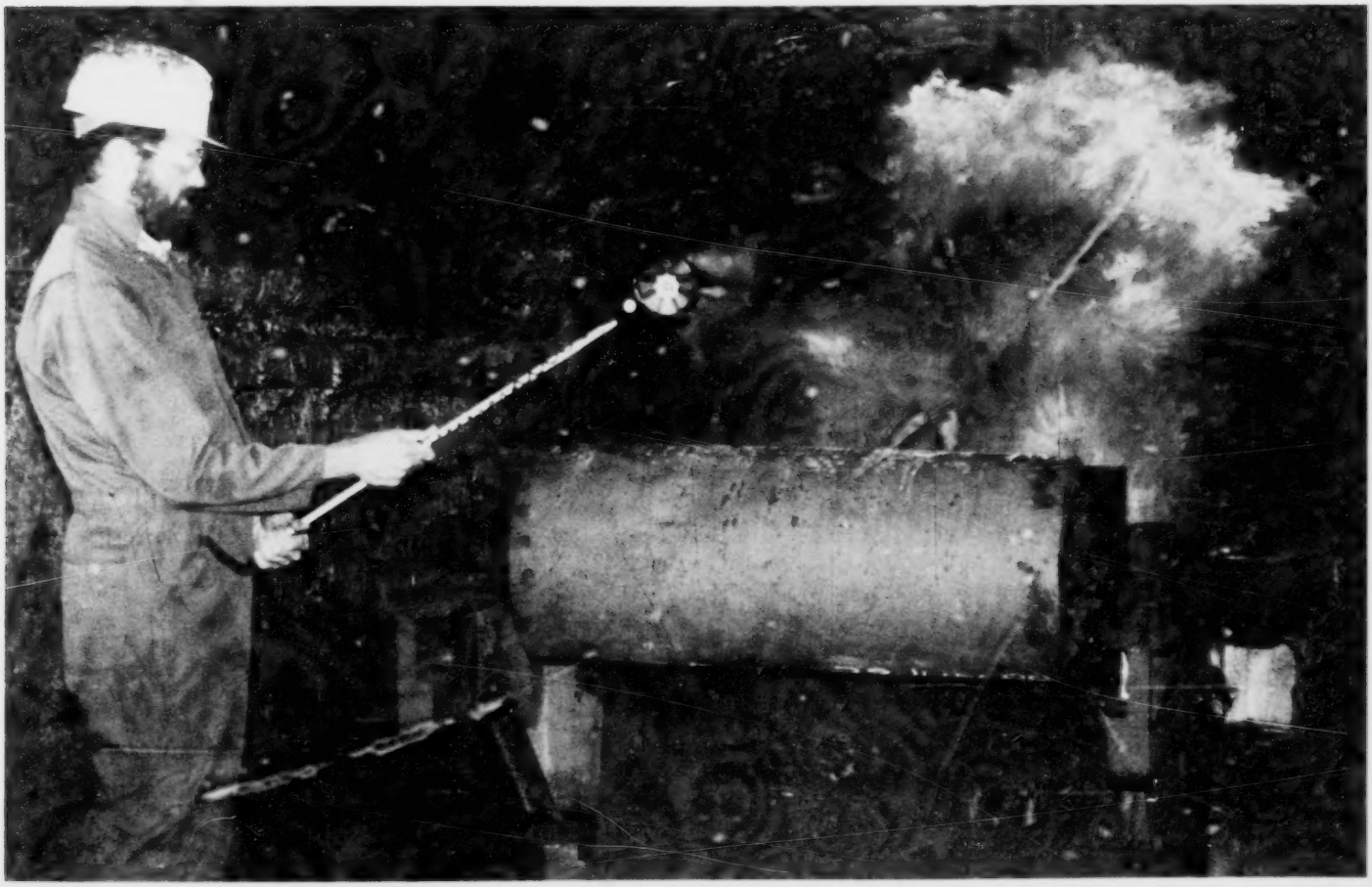
A large-scale spontaneous combustion facility was constructed to study the self-heating process in a 15-ton coalbed, simulating the gob area of a mine. The insulated coalbed is instrumented with thermocouples and gas sampling lines, and a metered airflow is passed through the bed. Experiments are underway with coals identified as having high spontaneous combustion tendencies, or obtained from mines that have had heating incidents.

The Bureau is actively cooperating with MSHA, National Fire Protection Association (NFPA) committees, and the mining community in the development of new or revised standards for the prevention, detection, and control of mine fires. Recent NFPA standards in this area address diesel fuel and equipment in underground mines, as well as the prevention of fires in bituminous coal mines.

Fire detection research is directed toward the development of improved mine fire sensors and intelligent systems to interface the fire detection system with the fire warning system, so that more prompt decisions can be made when fire emergencies occur. Such systems are expected to pinpoint whether the fire is smoldering or flaming, determine how the ventilation air velocity is being affected, help to choose the safest escapeways, determine the degree of toxicity of the combustion products, and obtain other information that can provide underground personnel with a higher degree of safety.

In the future, automatic fire detection systems use will be expanded to provide protection for other key mine areas, such as trolley entries, shops, and fuel storage areas. Many of these systems may be passive, nonelectrical systems employing fiber optic technology to explore the mine atmosphere for fire gases and smoke, methane, and other gases for which detection is of great importance to safety.

The Bureau has long cooperated with industry, MSHA, and others involved in mine fire research to address problems such as fire detection in mines operating diesel-powered equipment and diagnostic techniques for assessing the combustion status of mines sealed because of fires. This type of cooperation and commitment can be expected to continue into the future as old problems are solved while new ones arise.



A Bureau researcher measures airflow to determine its effect on the speed at which conveyer belt material burns.

Conserving Strategic and Critical Minerals

Strategic and critical materials are defined by the Strategic and Critical Materials Stockpiling Act of 1979 (Public Law 96-41) as those that are needed to supply the military, industrial, and civilian needs of the United States during a national defense emergency and whose supplies are dependent on imports.

Although the United States is fortunate in having adequate deposits of metals and minerals for many of its civilian and defense needs, some highly important metals and ores have import dependence approaching 100%. In most cases there are domestic deposits, but they are either low grade, complex, or too small and scattered to be economically mined and processed. Among the critical metals are aluminum (including the ore, bauxite, and the intermediate material, alumina), chromium (including ferrochromium alloy used in steelmaking), cobalt, columbium, copper, fluorspar, iron ore, lead, manganese (including ferromanganese and ferrosilicomanganese, used in steelmaking), mercury, nickel, phosphate, the platinum-group metals, tin, titanium, tungsten, vanadium, and zinc. The United States is not highly dependent on imports for copper, iron ore, lead, phosphate, or titanium, but these metals are considered critical because of their importance to the economy and national security.

In 1983 the Congressional Budget Office (CBO) reported four of the strategic and critical metals—chromium, cobalt, manganese, and the platinum-group metals—as being high risk; i.e., supplies were particularly vulnerable to political or economic uncertainty. The U.S. Bureau of Mines, throughout its existence, has conducted research on all of the strategic and critical metals. However, in response to the CBO report, a specific research program element was identified to deal with these four metals. Some ongoing projects were included in this element and other projects were instituted to implement new ideas and alternatives for the recovery of these metals from domestic sources. Emphasis was given to secondary resources as well as primary resources.

Additional metals continue to be identified for similar research emphasis. The Comprehensive Anti-Apartheid Act of 1986 (Public Law 99-440) essentially banned import of minerals and metals produced by South African parastatal organizations. The United States imports substantial quantities of chromium, manganese, and platinum from the Republic of South Africa.

However, section 303(a)(2) of the act provided an exemption from these terms if the President certified to the Congress that the quantities essential for the economy or defense of the United States are unavailable from reliable and secure suppliers. On January 7, 1987, the Secretary of State certified that the following qualified for this exemption: andalusite, antimony, chrysotile asbestos, chromium (including ferrochromium), cobalt, industrial diamonds, manganese (including ferromanganese and ferrosilicomanganese), platinum-group metals, rutile (including titanium-bearing slag), and vanadium (including ferrovanadium). Subsequently, the Department of Defense issued a list of 22 "high-tech" materials it considered essential to its needs. In addition to metals already identified, the list included indium, gallium, rare-earth metals, tellurium, rhenium, yttrium, bismuth, hafnium, selenium, beryllium, scandium, zirconium, cesium, and strontium.

Although the United States has a large cobalt resource at the Blackbird deposit in Idaho, the high arsenic content makes it uneconomical to process. The most promising domestic cobalt sources are spent copper leach solution, Missouri lead ore flotation byproducts, superalloy scrap, and ocean minerals. A cooperative project with a lead producer has demonstrated the feasibility of producing a high-cobalt concentrate from Missouri lead ore, using Bureau-developed column flotation technology. Recovery of this product also improves the byproduct copper concentrate from which it is recovered. Research continues, in cooperation with other Government agencies and academia, on the collection of samples from the U.S. Exclusive Economic Zone, characterization and analysis of those samples, and the development of beneficiation and extraction methods.

There are no domestic chromium deposits likely to be commercially exploitable. The Stillwater chromite deposit in Montana can only be mined when production is subsidized. Bureau research, therefore, is concentrated on recovery of chromium and cobalt from secondary resources, especially superalloy scrap. One promising technique involves melting the scrap with sulfur to form a matte, and then selectively leaching nickel, cobalt, and chromium.

Sulfur content of the matte has been shown to be an important variable. At sulfur levels below 4%, over 99% of the nickel, cobalt, and iron are easily leached, along with 85% to 95% of the chromium and molybdenum. At sulfur levels up to 28%, chromium extraction drops sharply, and other metals somewhat. On the other hand, mattes made with less than 4% to 7% sulfur are difficult to grind. Another technique is to melt the scrap into anodes from

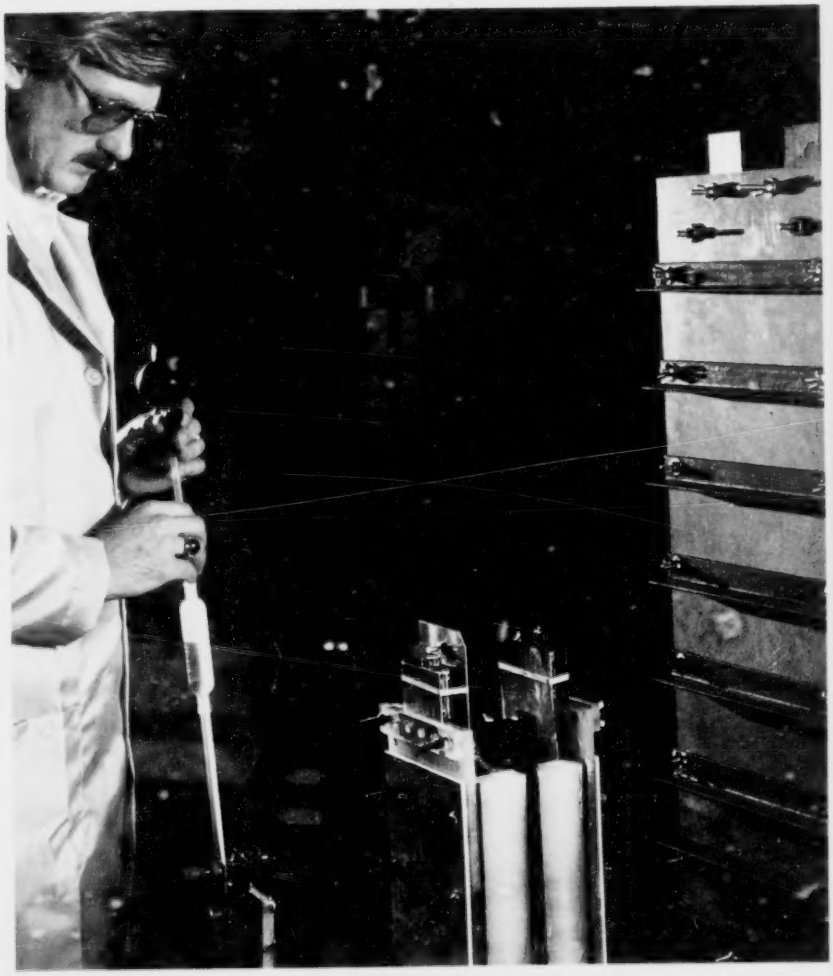
which a cobalt and nickel alloy is recovered electrolytically. Methods also are being devised for rejuvenating spent solutions used to pickle stainless steel, recovering chromium and nickel as products instead of precipitating them as a hazardous waste sludge.

Manganese is vital in steelmaking as a desulfurizing agent and to add toughness to the steel. There are a number of domestic resources, but they are low grade, uneconomical, and manganese recovery is low when they are processed by existing technology. Promising Bureau research has shown that the use of low-grade solid reductants such as bituminous coal, charcoal, or coke breeze can prereduce the manganese in a low-grade ore. When followed by smelting in an electric arc furnace, this results in a satisfactory ferromanganese product.

Piles of steelmaking slag represent another source of manganese. While current steelmaking technology results in approximately 12 pounds of manganese being discarded in this slag for every ton of finished steel, larger amounts were discarded in this slag until the 1950's. Bureau research is investigating acid leaching methods to recover this manganese, including the use of fluosilicic acid, a waste product of the phosphate fertilizer industry.

Ocean minerals also contain substantial amounts of manganese, along with cobalt, nickel, and copper, and Bureau researchers are examining methods for recovering these values economically. The use of bacterial leaching for the recovery of manganese from its ores has possibilities and also is being investigated.

The Stillwater Mining Company is producing platinum-palladium concentrates from ore mined at the Stillwater Complex in Montana, but they are being shipped abroad for refining. Bureau research has demonstrated technology for efficiently recovering these metals from concentrates and it is hoped that when the scale of operations justifies a domestic refinery, this technology may be adopted. Meanwhile, recovery of platinum-group metals from spent automobile catalytic converters remains a high priority for Bureau research. Efforts are directed toward a leaching procedure that would be applicable to relatively small regional recyclers. It is estimated that over half of the spent converters are being salvaged now, but about 70% of the recovered catalyst is being shipped abroad for refining.



Bureau technology to regenerate spent stainless steel pickling solutions may permit the annual recovery of approximately 1,000 tons of chromium and 500 tons of nickel in stainless steel pickling solutions now disposed of as waste.

Robotics and Automation

One thing our national security depends upon is an available and secure supply of energy. Domestic coal makes up 82% of the Nation's energy supply, yet we have not only become highly dependent upon foreign oil as an energy source, we are rapidly losing our ability to quickly utilize our abundant energy resources of coal without undergoing great economic and sociological hardships. This can result in foreign competition leading to more foreign dependency, the closing and sterilization of domestic mines and reserves, the attrition of the scientific and technological base in mining, and in general, a loss of our ability to respond to rapid changes in foreign energy supplies.

The United States possesses one-quarter of the world's recoverable coal reserves, the largest of any single nation. Of these reserves, two-thirds lie deep underground. If we are to recover these reserves, the continuous mining method is expected to remain an important extraction technique well into the future, since it is very versatile and is also used for longwall development. Further, developments for the continuous mining method should also have application to other systems; e.g., coal-rock interface detection technology will have direct benefits on a longwall shearer.

Continuous mining machine productivity is far below design capacity. In an advancing room-and-pillar operation, theoretical production for a continuous miner can be as high as 3,000 to 5,000 tons per 6.5-hour operating shift. In practice, only 300 to 500 tons per shift is realized and actual machine cutting time is 30 to 40 minutes. The remainder of the time the machine is idle because of various delays.

An improvement in the production rate could drastically change the economic situation. A 10% increase in machine productivity for a mine running five continuous mining sections, two shifts a day, and selling coal at $25 per ton, would realize an increase in annual income of approximately $2 million.

To increase the efficiency in U.S. minerals extraction, and to make sure that national security mineral needs are met, U.S. Bureau of Mines research is focusing on increasing the effectiveness of coal mine equipment. Initially, a system for an underground room-and-pillar continuous mining sections will be researched.

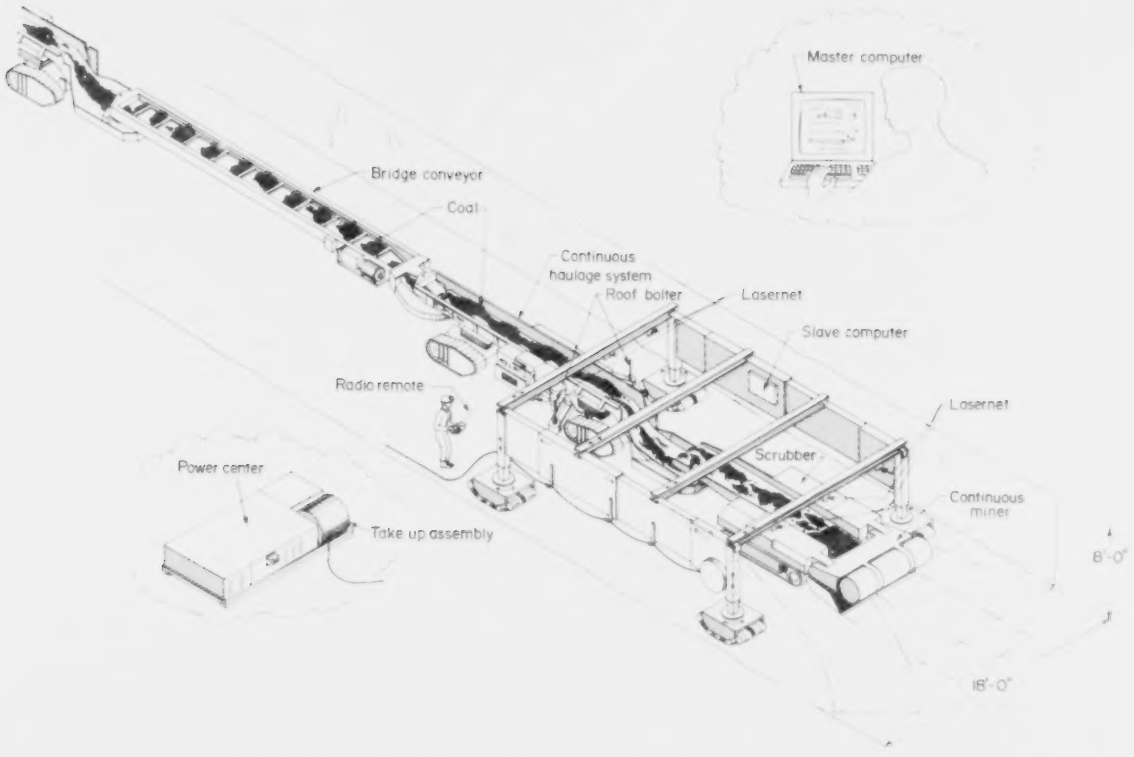
The Bureau is addressing the problems of safety and efficiency through the application of high technology, artificial intelligence, and robotics. The robotic technology being investigated is the control of the mining system through sensors and artificial intelligence, not replacement of the miner with a humanlike machine. Specifically, the research is focusing on completely robotic continuous mining, including an autonomous-robotic continuous mining machine, autonomous continuous haulage, and autonomous roof bolting, that would relocate workers from the face area to a safe supervisory control station, and increase extraction efficiency by 40% by the year 2000.

With the goal of 40% increase in efficiency of continuous miner operations, the following restrictions on efficiency in current continuous mining have to be recognized: (1) the frequency of machine failures and the mean time to repair machines, (2) the inefficient operation of mining machines by human operators, and (3) the inefficient management of resources at the face by humans.

According to a Bureau study, continuous mining machines have a mean time between failures of 6.2 hours and a mean time to repair of 2.2 hours, making the machine available only 73% of the time. Machines break down often and they are difficult to repair. Frequently a trial-and-error procedure is used to troubleshoot a problem. Adequate failure diagnostics would reduce repair time, and a failure prediction capability would reduce failures during production time; this would increase time available for production.

A frequent cause of failure is that present-day mining machines, which are very powerful, often having in excess of 600 hp, are often operated beyond their design limits. If this abusive operation could be prevented, failure rates would decrease and productivity would rise. The actions of the machine can be further defined and controlled to eliminate inefficiencies owing to the inexperience of the continuous miner operator. The result would be better control of bottom and top, straighter entries, and the more efficient use of available machine power in the cutting of coal.

Another item restricting efficiency is that existing equipment is not being efficiently utilized by the available labor. There is no effective scheduling, proper planning, or advance place preparation on most sections. Underground supervision may be overtaxed with the responsibilities of health and safety, section planning, equipment utilization, labor problems, equipment reliability, ground control, section supplies, and compliance with Federal, State, company, and union contract laws, rules, and regulations. There is also a lack of proper efficiency training.



Remote control of mining machines would relocate workers from the face area to a safe supervisory control station.

An important improvement to section productivity lies in application of improved management systems and procedures. With proper planning, organizing, and control, great strides can be made in productivity.

A common objective of improved machine performance and management is the conversion of delay and idle time into active production time by improving the extraction hardware, as well as improving the efficiency management of the mining activities at the face. The Bureau program on automation and robotics addresses these issues. A robotic continuous mining machine will reduce causes of low productivity in current continuous mining operations.

Projects under the Bureau's automation and robotics program are addressing guidance technology for navigation of autonomous mining vehicles; expert systems for reduction of mining machine downtime caused by electrical, mechanical, or hydraulic failures; intelligent control systems for autonomous mining; new techniques and intelligent signal processing for coal interface detection; natural language processing and computer graphics for worker-machine interfacing; and robotic technology for other mining functions. An immediate short-term goal is to develop and evaluate technology for an autonomous-robotic continuous mining machine.

In the 2 years since the start of the program, significant progress has been made. Accurate computer control of a continuous mining machine has been established. Sensing systems for machine diagnosis, coal-rock interface detection, and navigation are now being evaluated and software to use the sensed information for intelligent control is being written. The goal is to have this technology evaluated aboveground and underground in the next 5 years so that manufacturers may further advance the technology and make it available to the mining industry.

Improving Steel Technology

Although more recently developed materials have received much attention, steel remains as one of the basic materials for a modern economy. The combination of excellent physical properties and relatively low cost make steel vital for many industries.

The domestic steel industry is passing through an era of rapid change because of shifts in demand patterns, changing technology, society's demand for control of pollution, and strong competition from foreign producers. Improved technology can help the steel industry become more competitive, use domestic resources that are lower quality than imported raw materials, and reduce environmental impacts, and can help other industries use steel more efficiently. U.S. Bureau of Mines research is aimed at a wide range of steel industry problems from primary raw materials to improved performance of final products.

Domestic iron ore reserves are relatively low in iron, compared with many foreign ores, and must be finely ground and processed to separate iron-bearing from undesirable minerals. The fine concentrate must then be agglomerated to be suitable as charge material for blast furnaces. In the United States, the fine ore is usually agglomerated into spherical marble-sized pellets. The strength and other characteristics of these pellets have a strong effect on the productivity of blast furnaces.

Bureau researchers have investigated the effects of the addition of various mineral and organic binders and fluxes to the pellets on the reducibility and high-temperature softening-melting characteristics of the pellets. Research demonstrated that pellets could be made with papermill sludge binders, a waste that is available near the pellet plants. The better pellets with sludge binders had slightly lower physical strength than those made with bentonite binders, but had higher porosity, reducibility, and a higher softening temperature.

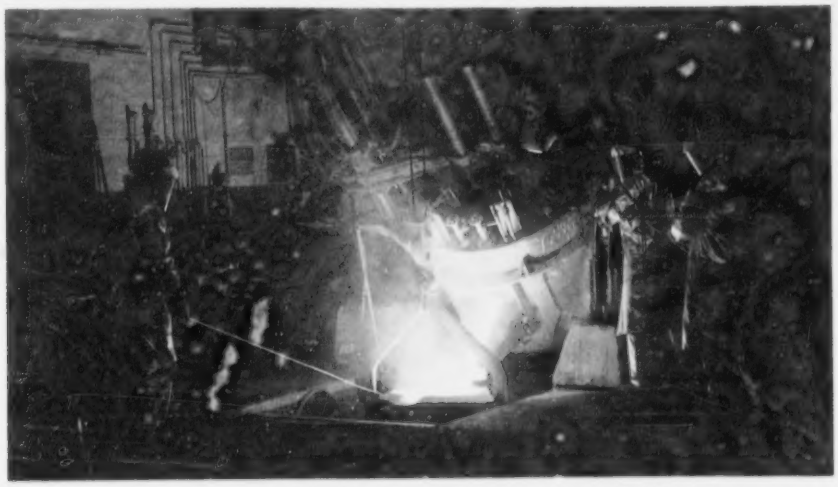
The Bureau is also investigating a process that would eliminate the need to agglomerate the finely ground iron ore concentrate. Researchers are adapting rocket engine technology for a process to produce iron from ore. In addition to eliminating the need for agglomeration, the process would eliminate the need for coke, and, because it would have a very high production rate in proportion to the size of the reaction vessel, it should have relatively low capital and maintenance costs per ton of capacity.

A large portion of the domestic steel industry does not use iron ore directly, but instead remelts iron and steel scrap in electric arc furnaces (EAF's). EAF's were first used in steelmaking for high-quality alloy steels that could not be produced economically using other methods. Today, they are used for over one-third of domestic steel production and for a full range of products from low-priced concrete reinforcing bar to high-value stainless and other specialty steels. Modern electric furnaces were one of the keys to the growth of the minimill steel industry. Minimills now dominate the markets for some steel products, because of their low costs compared with those of integrated mills producing steel from ore.

Rocket engine technology has been adapted for a new rapid rate smelter for iron ore.

Commercial electric furnaces use very high current arcs to produce steel from ferrous scrap. These arcs are similar to controlled lightning strikes and carry a large amount of power. Melting is the most energy intensive and noisy portion of the EAF steelmaking cycle. Rapid fluctuations in voltage and current increase energy consumption, result in erosion of furnace refractory linings, decrease productivity, can disturb the electrical power network, and cause environmental noise problems for workers. Improved arc stability and more effective power transfer from the power supply to the material in the furnace are required.

Research to date has shown that physical modifications to the electrodes can provide a quieter arc. Furthermore, investigations are underway, using extremely high speed movies and computerized data acquisition, to determine the reasons for instabilities in the arcs. Understanding the reasons for the fluctuations in the arc will allow scientists to predict the changes in the arc that cause noise and waste. This in turn could result in the ability to control the arc, thereby reducing energy consumption and increasing life for furnace components.



Better understanding of the instability of arcs in electric steelmaking furnaces may help reduce energy consumption, noise, and equipment wear.

The Nation's economy benefits not only from improved production technology, but also from improved materials that are more efficient in use. Wear and corrosion cost the United States tens of billions of dollars each year. As primary structural metals, steel and cast iron are involved in a significant part of this loss. Also, current technologies for increasing the wear and corrosion resistance of ferrous metals frequently use the addition of strategic and critical alloying elements, particularly chromium. About 70% of U.S. chromium consumption is used for stainless steels. Additional chromium is used in other alloy steels and cast irons, frequently in order to improve wear resistance. Chromium plating is another technique commonly used to protect steel from wear and corrosion.

The Bureau is studying fundamental aspects of wear to improve performance of materials and to develop new materials less reliant on strategic and critical materials. In studying wear in mining equipment, the Bureau has developed a standard methodology to help correlate the results of laboratory tests and performance in real world situations. Theoretical studies are being conducted to improve the understanding of wear. Fracture mechanics studies indicate that particle shape in metal microstructures should have a significant effect on wear. Crack propagation studies have resulted in an abrasion-resistant alloy having a greatly increased impact life. This material contains only half as much chromium as the highly alloyed cast irons that are used throughout the minerals industry.

In other work, the Bureau is studying fundamental aspects of corrosion. The program includes investigation of the effect of structure on the corrosion resistance of various iron base alloys and of the protective passive film on iron-chromium alloys such as stainless steel. Alloy research has led to the development of corrosion-resistant and high-temperature oxidation-resistant steels with greatly reduced chromium content.

The use of galvanized steel has increased dramatically in recent years, particularly by the automotive industry, which specifies galvanized sheet for many of the parts of current automobile bodies. Recently available electrogalvanized sheet steel has provided good resistance to corrosion yet has the good paintability necessary to retain the fine surface finish desired by automobile buyers.

However, the increased use of galvanized steel is resulting in increased zinc in scrap. Most of this zinc is collected by pollution control equipment in the dust generated by steel furnaces that melt the scrap. Disposal of the dust is a problem for the steel companies and is, at the same time, a waste of a potential resource. The problem is particularly significant for EAF plants, which depend almost entirely on scrap for their iron raw materials, and whose dust is usually classified as a hazardous waste.

The Bureau is working on technology to leach zinc from EAF dust and to remove deleterious impurities from the leachate. The purified solution can be used as a source of zinc in electrogalvanizing cells or can be further processed to produce solid zinc products. In Bureau laboratory tests, electrogalvanized steel with either zinc or zinc-iron coatings has been produced using the recovered zinc-bearing solutions. The galvanized steel products are comparable to commercial products in ductility and adhesion of the coating and in protection of the steel from corrosion.

Advanced Rock Fragmentation

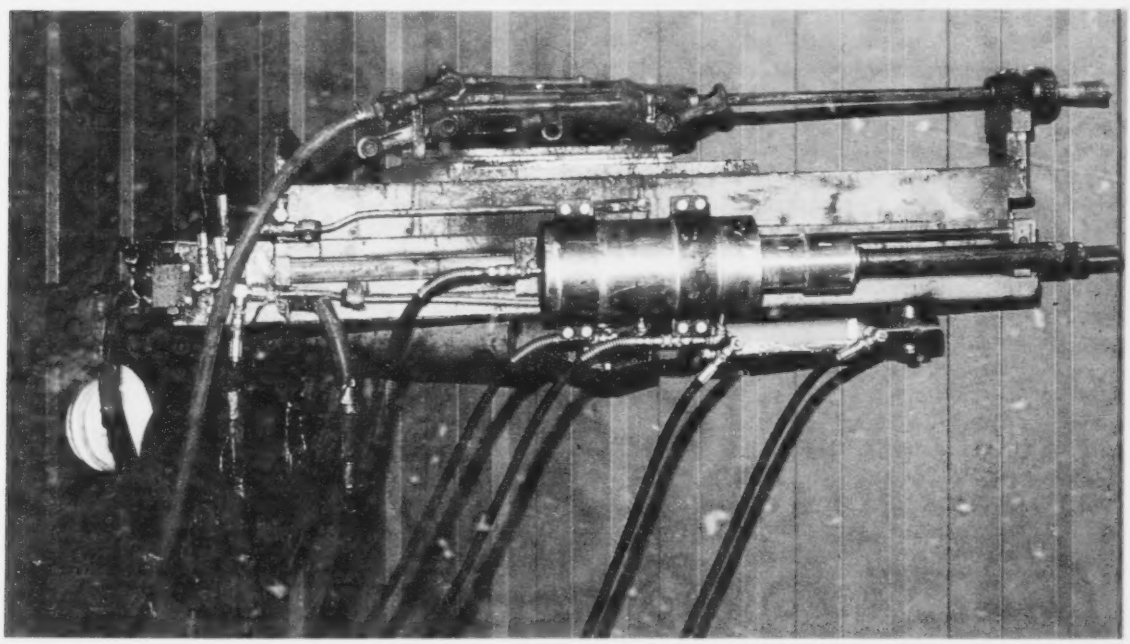
The automation-robotics research focused on coal mining applications will eventually serve hard-rock mines. A long-term goal of the U.S. Bureau of Mines is to provide technology that will enable mining companies to cut or fragment ore so that it can be conveyed out of a mine with few miners underground. Reduced exposure to hazardous underground conditions will improve miner safety. Eliminating drilling and blasting as a primary means of excavating ore will also reduce wasted time in mining because drilling and blasting is very cyclic.

The key ingredient in such a mining system is the cutting machine. Although continuous mining machines readily cut soft coal, no counterpart exists for cutting hard rock. Massive tunneling machines that bore large horizontal holes for transportation tunnels can advance very fast in a straight line. They are, however, too inflexible and cumbersome to follow ore veins underground. They also consume much energy, relying on massive frames and large reaction forces to crush the rock.

Until a small and efficient hard-rock cutting machine is developed, it will be impossible to fully automate hard-rock mining. To reduce machine size and increase maneuverability, the Bureau concentrated on exploiting tensile forces in cutting rock. Although rock can be extremely strong in compression, it is very weak in tension. The Bureau has developed two concepts of cutting rock in tension—a ripper miner that uses one big bit to cut the rock and a wedging device to split the rock from slender boreholes.

The ripper miner essentially uses a large bit forced through the rock in an arc. After the first pass through the rock, the bit cuts mostly in tension, separating large chips from the rock face. The experimental model of this device has readily cut rocks of a medium strength. Improvements in cutter configuration will hopefully allow the concept to work in hard rock. The Bureau also successfully tested a concept of heating the rock with microwaves to soften it for cutting with mechanical cutting machines.

The second concept of mechanically breaking rock in tension is the radial splitter. The Bureau's device is based upon a splitting machine that miners have used for many years to trim underground openings. In the Bureau's method, two hydraulically operated wedging mechanisms inserted into a narrow hole are activated to spall slabs of rock surrounding the hole. The device can be mounted on the same stand as a drill, making a portable and nearly continuous extraction device.



Bureau researchers developed a concept for excavating openings in rock using a radial splitter, shown here mounted beside a percussive drill. In this concept, a slender hole is drilled into a rock face and the splitting device is then inserted and activated to pull a plug of rock from the face.

Tests with a laboratory-scale radial splitter showed that it readily removed 500 pounds of material per pull; repeated operations created 4- by 5-foot openings in blocks of concrete, as shown here.

Automating Froth Flotation

Ores as mined are a mixture of minerals, some of value and the rest waste. Typically it is both possible and necessary to physically remove a portion of the waste minerals prior to chemical extraction of the metals. In the great majority of situations this physical separation is carried out by grinding the ore to break the valuable minerals away from the waste, which is followed by froth flotation.

As usually practiced, flotation is a process wherein the valuable mineral particles are caused to attach themselves to air bubbles that are rising through a slurry of water and ore particles while the waste minerals sink to the bottom of the flotation tank and are removed. The rising bubbles with attached particles of valuable minerals form a froth at the upper surface of the water. The froth is skimmed off and the valuable minerals are recovered. An impeller, much like an egg beater, forms the air bubbles by agitation.

While the technology works very well, automation of froth flotation has the potential to markedly increase both the metal content of the concentrate product as well as the amount of metal recovered from the ore. Furthermore, automation should decrease the use of flotation chemicals per ton of product. Thus automation not only increases process efficiency and thereby decreases costs, it also decreases the environmental impact associated with metals production by increasing the amount of metal produced per acre of land disturbed and per ton of waste produced.

U.S. Bureau of Mines flotation research has focused on sulfide minerals because they are the most frequently concentrated by this technique and are economically critical to the Nation's supply of primary metals. This research has indicated that reactions occur between the chemicals dissolved in the water and atoms on the surface of a mineral. These reactions affect the ability of the mineral to become attached to an air bubble and can in turn be affected by voltage differences between the solution and the mineral surface. Controlled amounts of chemicals can be added to the aqueous solution that produce the effect of a voltage change. This is called changing the reduction-oxidation (redox) potential in the flotation cell.

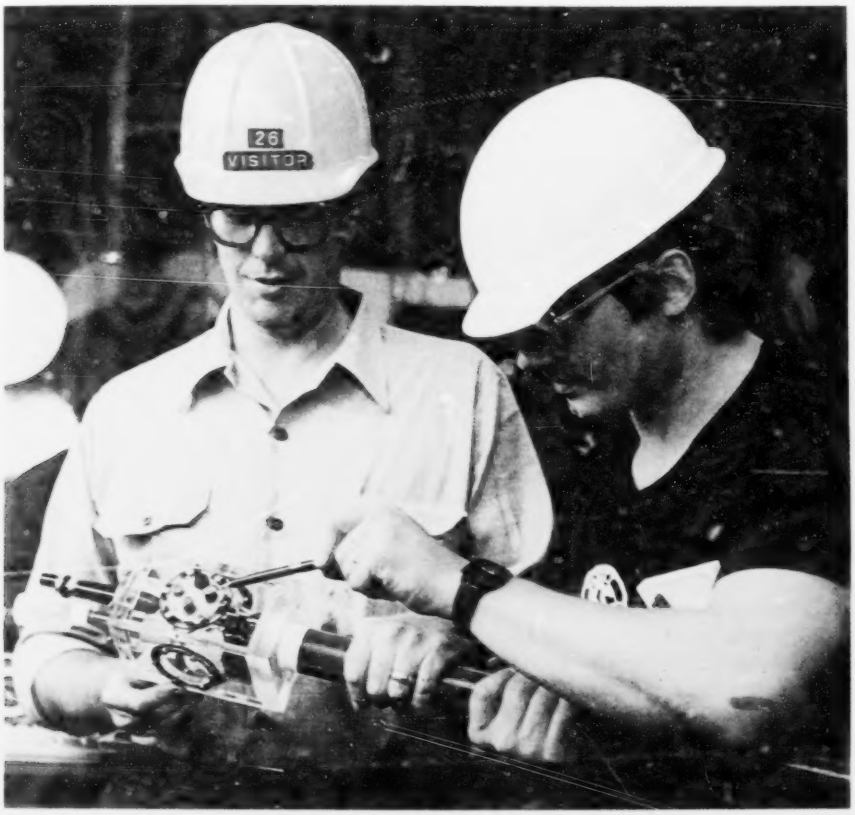
Research conducted during 1988 concentrated on three main subjects: (1) understanding the galvanic influence of grinding media on the flotation of sulfides, (2) further elucidating the relationship between redox potential and flotation, and (3) preparing to test column technology in a commercial environment.

Research was initiated to determine the effect on flotation of galvanic interactions between grinding media and sulfide minerals. Chalcopyrite was the first sulfide mineral selected for study. High-carbon, low-alloy steel (HCLA) and stainless steel were chosen as representative grinding media. Results to date indicate that the chalcopyrite would act as a cathode and the steel as an anode; i.e., the HCLA will dissolve and the surface of the chalcopyrite will be reduced. These conditions will affect other adsorption of the organic chemical on the mineral. For example, if the conditions are too reducing, i.e., the redox potential is negative, some organics will not adsorb on chalcopyrite.

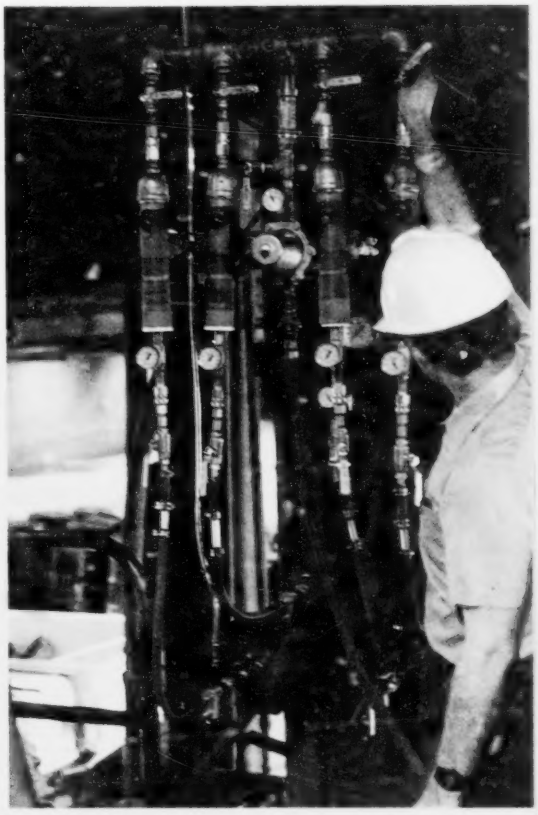
Based on the understandings resulting from previous basic research by the Bureau, a sensor probe was designed and constructed that would measure the redox potential and the pH of solutions in a flotation cell. This probe was tested in a column flotation cell at a gold mine to determine whether additional gold could be recovered from two different types of tailings, one from the carbon-in-leach (CIL) process. These industrial trials indicated that redox potential and pH measurements could be coupled to serve as a basis for controlling the flotation cell to achieve a desired concentrate grade and recovery. The control was through sodium sulfide and acid-base additions.

In addition to learning more about the relationship between redox potential and flotation, the work at the gold mine was done to check out the control system (including the probe) to be used with a portable column constructed by the Bureau. This column, which is 12 inches in diameter and 38 feet tall, will be transported to various sites to evaluate the performance of both column flotation and the control system under a variety of industrial conditions. The plexiglass column is equipped with solenoid-actuated ports at 2-foot intervals for automatic sampling of the slurry and froth. These sampling ports can be actuated simultaneously to provide an analytical profile of the mineral distribution within the column. Ports also are available at 2-foot intervals for installation of probes.

Research was conducted with the Bureau's experimental columns on a number of mineral systems. Results from column flotation of the gold ore tailings showed (1) diesel oil promotes gold recovery when used at appropriate levels, indicating that some of the gold being recovered is probably associated with the gold-bearing carbonaceous material, (2) excess diesel oil will kill all froth, and consequently decrease recovery,



Examining a sensor probe before connection to a computer and insertion into an industrial flotation cell. Bureau scientists pioneered controlling flotation by electrochemistry instead of by chemicals such as cyanide.



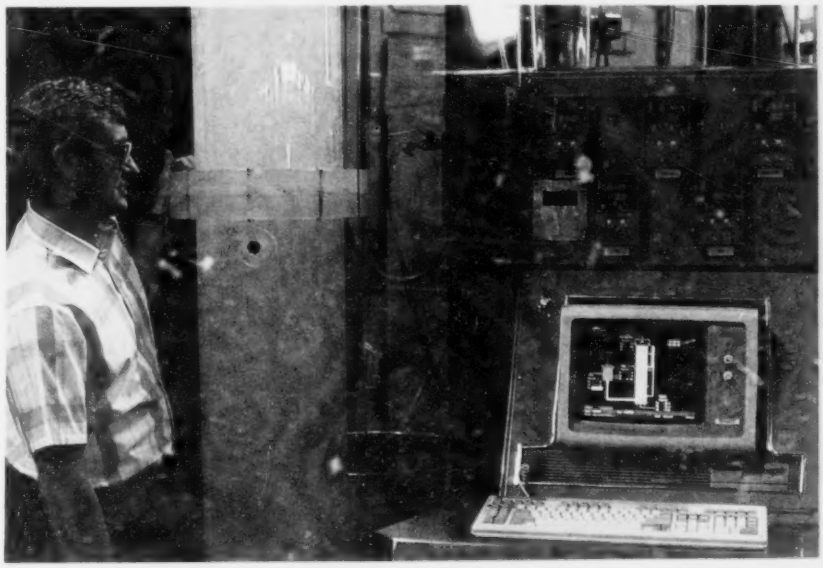
The Bureau also developed a new bubble generator that maximizes recovery of ultrafine particles normally lost in column flotation.

and (3) a maximum of 36% of the gold present in the tailings was recovered in a concentrate containing 0.49 ounce of gold per ton.

Column flotation of a sulfur ore increased the concentrate grade to 93.2% as compared with a maximum of 70% for conventional flotation. Recovery was increased slightly from 90% to 92.6%. A commercial installation is planned as a result of this work.

Similar improvements were obtained for spodumene tailings. Column flotation produced a concentrate containing 65% spodumene compared with 40% to 45% concentrate produced by six stages of conventional flotation. Spodumene product grade must be in the upper 50% range in order to be readily salable.

An economic comparison of conventional flotation to column flotation for fluorspar ore showed that column flotation will produce a higher grade product at a lower operating cost for plants with equivalent installed capital cost. Because of the higher grade achievable, the column flotation product was found to offer both a market size and a price advantage over conventional flotation.



The technology resulting from putting these concepts together and automating the process is expected to save a typical domestic copper producer several million dollars annually.

Reducing Hazards From Mountain Bumps and Rock Bursts

A mountain bump is a sudden and sometimes catastrophic failure in a coal mine structure due to excessive ground pressure. Rock burst is the term used to describe a similar catastrophic failure in a metal mine. These types of rapid ground failures are capable of causing multiple injuries or fatalities to miners as well as damaging a working section. In coal mines, a mountain bump can be accompanied by a large volume of gas, usually methane, and coal dust. In addition to the potential for injury from flying coal and rock, such an event, usually referred to as a gas outburst, can have the potential for injury from an explosive mixture of methane, air, and coal dust.

The U.S. Bureau of Mines is developing innovative rock mechanics approaches to solving mountain bump problems. Field studies are being conducted at underground coal mines in Virginia, Colorado, and Utah to develop mountain bump monitoring and mitigation techniques. Research results have shown that retreat longwall mining of coal seams associated with rigid strata and under thick overburden could result in bump failures of gate road pillars. These studies indicate that mountain bump hazards can be reduced by appropriate mine design.

When a rock mass is subjected to the changing conditions of load and stress caused by mining, small-scale adjustments occur that release seismic energy. This energy, when audible, is called rock noise. Miners have known for years that "rocktalk" can be a warning of impending failure. Microseismics—the study of rock noises—represents an important aspect of the Bureau's research on prediction of catastrophic ground failures.

Anomalous microseismic activity in mines has outlined volumes of rock in advance of their experiencing catastrophic failures such as mountain bumps, outbursts, and rock bursts. However, microseismic activity has been found with rock volumes that are simply adjusting to changing stresses without the occurrence of a catastrophic failure. Rock bursts have occurred also without apparent anomalous microseismic activity in advance of their occurrence. Therefore, the primary challenge to microseismics research is to distinguish between the anomalous activity leading to a mountain bump or rock burst and the activity merely associated with normal stress readjustment. In addition, we must look for anomalies in those cases where a bump occurs with no apparent anomalous microseismic activity.

The full understanding of microseismic techniques and analysis holds the promise for the mining industry to (1) consistently outline potential areas of ground hazard in advance, (2) suggest proper control techniques, such as destressing, to avoid a catastrophic failure, (3) evaluate the effectiveness of control techniques, and (4) if the failure cannot be avoided, provide warning in sufficient time to allow the miners to get to safety.

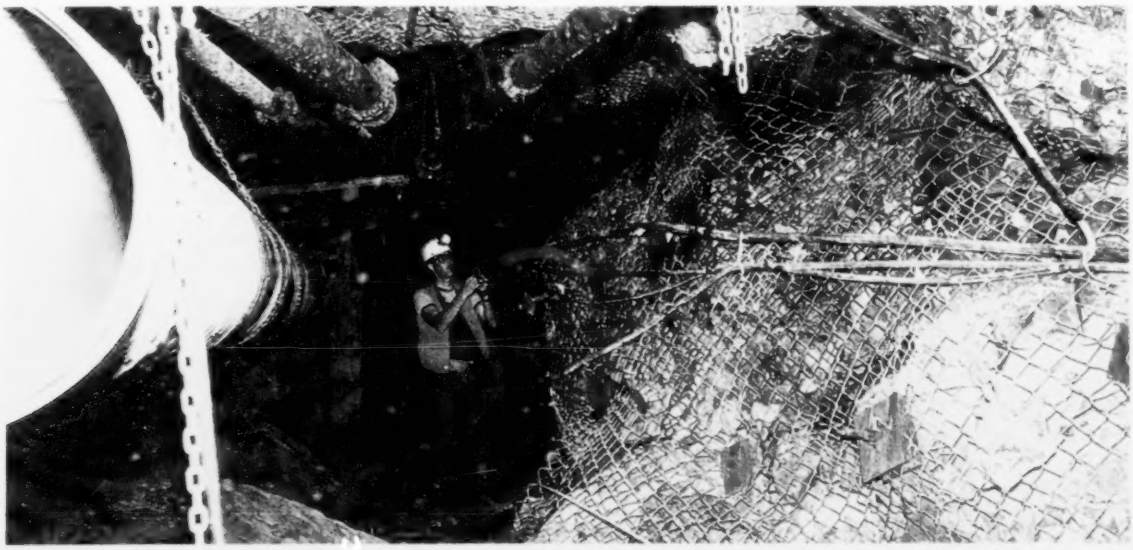
Mountain bump microseismic research has been conducted at two coal mines in the western coalfield and one mine in the eastern coalfield. Rock burst microseismic research continues at the Galena Mine and Lucky Friday Mine in northern Idaho. Past microseismic monitoring in coal was hampered by reliance upon an analog tape deck recording and playback system for which data reduction was very labor intensive and time consuming. The current research goal is to automate microseismic data collection and analysis in coal mines.

Bureau researchers have developed and evaluated two automatic digital recording systems for collecting coal mine microseismic data, determining arrival times of signals at each geophone, determining signal validity, locating sources of valid events, and displaying the results on a computer screen or hard copy. By virtue of its lower price and superior performance, one of these systems was chosen for further evaluation in western Colorado coal mines.

The Bureau has been engaged in research for prediction and control of rock bursts in deep metal mines for many years. Microseismic research at ASARCO's Galena Mine, Wallace, ID, has resulted in technology that has warned miners of imminent rock bursts on several occasions, giving the company sufficient time to evacuate the hazardous section.

The success of this research has come through the use of dense geophone arrays to monitor individual stopes in underground mines. The Bureau has traditionally monitored a few local stope areas with dense arrays of microseismic sensors. This provided high sensitivity and high location accuracy. However, when efforts were made to apply this research product in the industry, the same number of sensors were often used to monitor an entire mine. Such an application scheme reduced sensitivity and accuracy of the monitoring system, thus reducing the usefulness of the data.

The Bureau has now designed and constructed modular stope monitoring systems



A rock burst in a deep silver mine in northern Idaho shattered the right rib of the drift and displaced it outward about 6 feet. The resin-grouted rebar bolts have been broken, but the wire mesh has kept the fractured mass of rock intact.

that maintain the dense sensor arrays in individual stopes, yet allow minewide monitoring. The Bureau has developed a method of connecting these modular systems together into a network system so that it is now possible for a mining company to monitor an entire mine while preserving the high sensitivity and high accuracy formerly available only in a research system. The prototype microseismic monitoring network system has been installed in the Galena Mine under a cost-sharing cooperative agreement between the Bureau and ASARCO, Inc.

Single-stope systems equipped with 32 arrival-time channels and 4 energy channels have been linked using a computer network and precision time synchronization. Each stope system has its own display and storage, but the information on any network computer is simultaneously available on all other network computers. A fiber optic cable to the surface of the mine and a high-speed modem will provide remote access to both real-time and archived data. The key feature of this concept is that the high accuracy and high sensitivity of the former single stope systems have been preserved while extending the monitoring to the entire mine. Network data will be available for studies of the effects of stope interactions and differing mine geologies. Beyond this, the network will provide a common medium for diverse research technologies. Near-future additions to the network will include a digital seismic system, a digital microseismic system, and advanced hardware and software for the interactive three-dimensional analysis of event locations overlaid on mine geology, geometry, and structure.

The use of microseismic monitoring networks also allows research efforts to incorporate other types of data such as local and regional seismic data, radon and microseismic emissions from fractures, and structure and geology data. There is optimism that a program of research incorporating such information can lead to significant improvements; first, to the fundamental knowledge of the causes and progression of failure events, and later, to improved forecasting and control methods.

Rock burst control techniques are also being explored by the Bureau to enable continued mining in areas where unstable ground conditions cannot be avoided. These techniques involve an effective modification of ground conditions. A potentially useful control technique involves using wire mesh held on the rock surfaces by rock bolts. In-mine observations indicate that rock shattered on the drift openings during a rock burst can be held in the wire mesh.

Unfortunately, the use of wire mesh throughout a mine is quite expensive. However, analysis of the waveforms produced by microseismic events offers promise of allowing the construction of rock burst hazard maps throughout a mine structure. These maps can be used to determine where a wire mesh needs to be placed, and can result in considerable cost savings to the mine. Experiments are now underway in northern Idaho mines to evaluate the benefits of various rock burst control techniques.

A New Initiative on Mineral Wastes: Seeking Better Definitions and Better Management

Growing national concern about environmental problems has challenged all U.S. industries. In mining, this challenge is to safely handle the large volume of waste generated as mining byproducts and yet maintain a competitive minerals industry.

The size and complexity of actual and potential problems are immense. Mine wastes include material removed to gain access to minerals, low-grade stockpiled materials, heap and dump leach piles, and wastes left after processing (which are usually in excess of 90% of the original volume). The mining industry has accumulated 50 billion tons of waste, enough volume to pave 10 six-lane freeways to the Moon, and is currently generating more waste at a rate of 1 to 2 billion tons per year.

Although most mine wastes are not presently considered sources of toxic contamination, many factors and conditions can lead to the release from wastes of metals, acids, and other chemicals and materials. Of particular concern are the heavy metals such as arsenic, cadmium, copper, lead, and zinc, which can cause adverse health and environmental effects at concentrations of a few parts per billion. This concentration level is frequently many thousands of times less than can be efficiently removed with most current mineral extraction technology. Ordinarily, these metals are bound into the matrix of soils or wastes and present no hazard. However, under certain conditions, these materials become mobilized and enter the environment as contaminants.

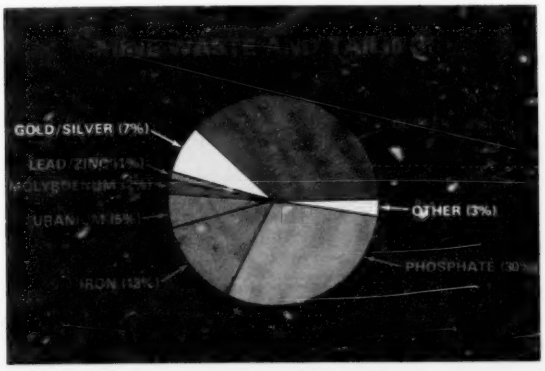
Most contamination occurs below the surface of the ground. It can vary considerably over small distances, fluctuate with time, and is often noticeable only after considerable damage has been done. Seepage from waste areas can contaminate drinking water supplies as well as severely affect local aquatic ecosystems. Levels of human exposure may be quite low, but increasingly, long-term, low-level exposures to metals are being linked with human illness. In one case, long-time, direct ingestion of lead resulted in elevated levels of lead in the blood of many people living close to a mine smelter. These levels were recently shown to be many times those capable of causing human health problems; as a result, this site has become one of the largest Superfund sites.

Because of the size and complexity of contamination problems and poor understanding of underlying causes, regulatory programs have not been effective in providing practical, long-term solutions. This is particularly true in the nonfuel mineral industry, which is the central focus of current U.S. Bureau of Mines efforts.

During past research, the decomposition of pyrite (iron sulfide), also known as fool's gold, has been shown to be a primary factor in the formation of acidic mine water and subsequent contamination associated with coal mining. Bureau-pioneered biotechnology utilizing biocides and engineered wetlands has provided significant solutions to controlling acid mine drainage problems from coal mines. However, in the case of wastes associated with metal mining operations, the presence of a larger variety of potentially hazardous compounds poses more severe environmental problems for which effective cleanup, control, and mitigation technology is not available. In addition to sterile acid waters, soils may be contaminated with toxic metals from mine wastes and smelter emissions, and toxic metal ions may be leached from the host minerals and contaminate surface and ground waters.

The nature and extent of existing and potential future contamination from metal mine wastes is a significant area of research. Acute problems have already been identified in several historic mining districts. These sites have been placed on the National Priorities List by the Environmental Protection Agency (EPA). These districts characteristically have large underground and surface workings, vast surface disposal areas, and diverse climatic, geologic, hydrologic, and mineralogic features. There is no systematic body of information and protocols that can be used to measure and predict the hazard potential of most mining and mineral processing wastes. In addition, there is little cost-effective technology to clean up and mitigate existing contamination problems other than waste removal and redisposal at approved sites.

To address these problems, the Bureau, under a new waste management initiative, is conducting research that will provide sounder scientific data on the characteristics of mine wastes and the factors that lead to soil and water contamination. This research involves a multidisciplinary approach that synthesizes the sciences of mineralogy, chemistry, hydrology, and geology. The program is balanced among (1) laboratory studies to identify the fundamental reactions and conditions that cause the dissolution and migration of toxic species, (2) field studies of contributing climatic, geologic, geochemical, and hydrologic factors, (3) modeling studies to develop safer waste management practices, and (5) the



Yearly volume

Overburden

Smelter residue

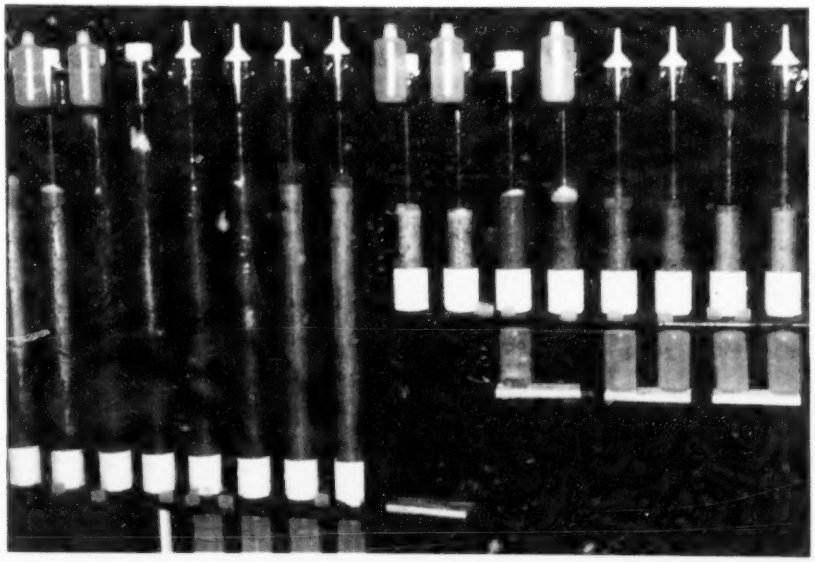
Leaching residue

Mining and mineral processing wastes range from low to high toxicity.

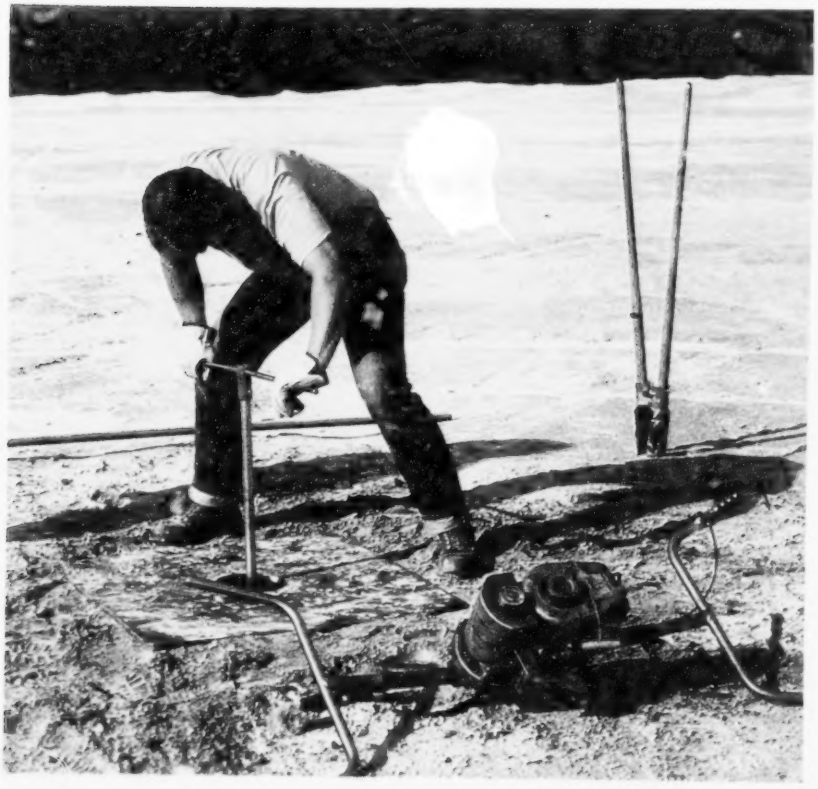
development of new extractive metallurgical technology to reduce the volume and toxicity of mine wastes.

Laboratory Studies. Fundamental studies are being conducted to obtain, on a molecular level, details of how mine and mill wastes undergo dissolution to release potentially toxic metal ions and the role that biological and geochemical processes play in these reactions. This information, coupled with site-specitic geologic and hydrologic data, is essential for the development of procedures to accurately assess the potential of mine wastes to adversely impact the local ecology or environment. It is also necessary for the development of better waste management practices and technologies that eliminate or minimize the dissolution and migration of toxic constituents.

Research is focused on the tailings from beneficiation processes. Sampling methodologies are being developed to obtain representative samples from heterogenous waste tailings and to enable accurate simulation of field conditions in the laboratory tests. Over 20 different metal mine tailings sites have been sampled and the



Fundamental studies of the dissolution behavior of mining and milling wastes are being conducted in column cells to assess their potential for releasing heavy metal ions to surface and ground waters.



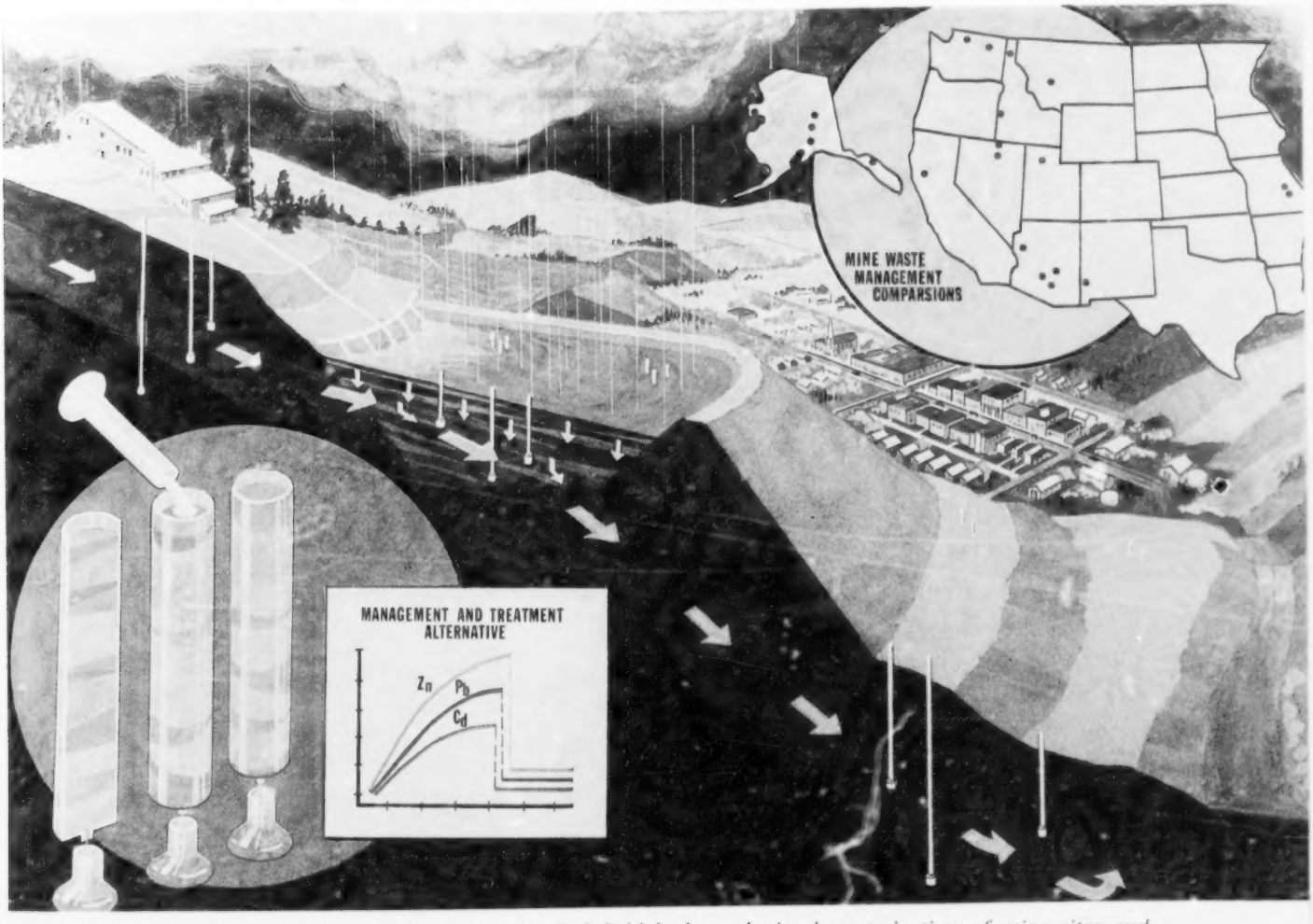
As part of a waste sampling program, hand-auger samples are obtained from mill tailings.

wastes subjected to hundreds of column leach tests. These studies have led to a much better understanding of the sampling methodologies and leaching procedures that must be used to obtain reliable and reproducible dissolution data. In addition, numerous factors have been identified that influence the dissolution and the migration of contaminants from tailings wastes. These include oxidation-reduction potentials, pH, salt content, degree of saturation, residence time, and microbial action.

Field Studies. In a parallel effort to laboratory studies, field research has used state-of-the-art monitoring of mine wastes to determine how contaminants are unlocked from waste material. Initial results indicate that many reactions occur in wet conditions above the water table in an area referred to as the unsaturated zone. Here, oxygen and water are available to decompose minerals into an acid solution, which further mobilizes contaminants. Transport of these contaminants is highly dependent on the characteristics of the material through which the contaminants flow and subsequent chemical reactions that can either increase contamination potential or relock the contaminants into a solid.

Modeling. Modeling studies are directed at developing a numerical system that can be used to evaluate the potential of mine waste to release contaminants to the surrounding environment. This work will eventually represent a synthesis of the results obtained from the laboratory and field studies. In addition, the impact of mining and mineral processing on water quality data in some of the historic mining districts is being obtained from a number of mining companies. These water quality data span longer time periods and statistical methods are being applied to identify similar geochemical features that contribute to contaminant migration. The development of models integrating reaction mechanisms and site-specific geochemical and hydrologic conditions will give industry and regulatory agencies a method to assess the contaminant potential of mine wastes and to develop more effective waste management practices.

Volume and Toxicity Reduction. In a cooperative effort with the University of Idaho, the Bureau is investigating a variety of problems at a large, integrated, lead-zinc operation. This operation is one of the largest and most complex Superfund sites in the country. Researchers are evaluating the best methods to handle metal-ion-laden acid mine waters and are applying new metallurgical techniques to these wastes with the goal of recovering enough metal to help offset cleanup costs. The underground fracture system in the mine is being evaluated to ascertain its effects on hydrogeology, specifically water



Future waste management practices will rely on detailed field hydrogeologic characterization of mine sites and fundamental laboratory studies of the chemical and mineralogical properties of the wastes.

inflow, as a means of predicting and controlling acid mine water production. Experiments are being run to recover metals from specific highly contaminated streams with a process that pretreats the water before it mixes with other, less contaminated streams inside the mine. A catalyzed hydrogen reduction process that uses platinum as a catalyst shows that complete removal of zinc is possible.

Other experiments involve the chemical removal of heavy metals from mine water. Tests using sodium borohydride to precipitate metals showed that almost all zinc could be removed. During treatment of acid mine waters leaving the mine, an existing lime treatment plant produces a sludge that is up to 40% zinc. A method to recover this zinc is being evaluated. A reducing agent (natural gas, coal, or activated carbon) mixed with the sludge at high temperature yields volatile zinc metal, which is then condensed as either elemental zinc or zinc oxide. Ferric chloride and thiourea were used to leach soil samples. This process has recovered 98.5% of the lead, 50% of the copper, 100% of the zinc, and 84.7% of the silver.

Research is continuing on this and other Superfund wastes as part of the overall waste management initiative. Because Superfund sites are pressing national concerns, there are many organizations involved in research, regulation, planning, and cleanup activities. Coordination of activities with these organizations is also a critical aspect of successfully reaching the Bureau's goals to ensure that national needs for raw and processed mineral products can be met. The challenges are to maintain a clean environment, satisfy the Nation's demand for mineral products, and at the same time permit multiple beneficial uses of the land, water, and natural resources.

Advanced Materials: Challenges and Opportunities

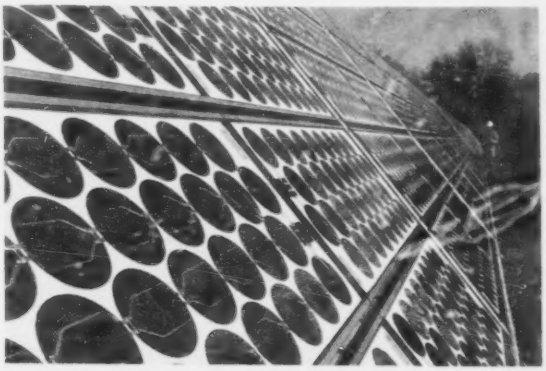
Advanced materials have come to mean much more than substances with special performance properties. They have become the media by which new technologies diffuse throughout industrial economies, with little separation between the material and the technology. Advances in materials science have become prerequisites for success in our most sophisticated technologies. These new materials no longer are just familiar substances altered to build objects. They are materials created in the minds of scientists, designed with the assistance of computers, and fabricated with robotics.

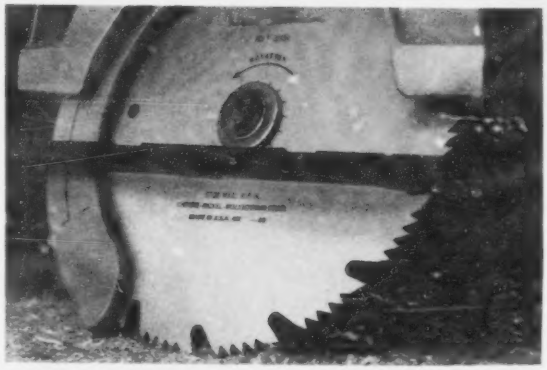
Advanced materials are engineered, sometimes molecule by molecule, often from plentiful, readily available minerals, either to perform an existing task better or to enable an entirely new task to be done. These materials come from opportunity-driven development, often in small, narrow applications rather than need-driven developments for high-volume application.

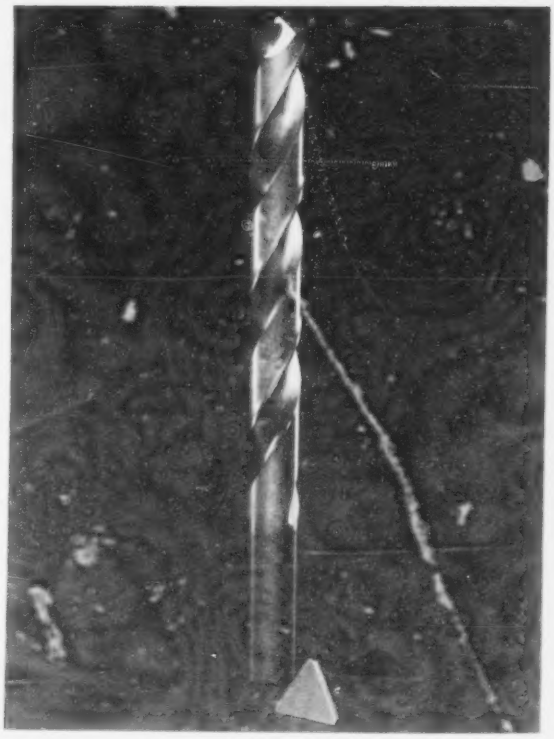
Traditionally, users had to adapt their needs to the properties of a material. Advanced materials are engineered to include the properties needed by the users. Today, the properties of materials can be predicted before they are made, and "recipes" for materials can be designed to obtain the properties desired for particular applications. As a result, advanced materials exhibit greater strength, higher strength-density ratios, greater hardness, and superior thermal, electrical, optical, or chemical properties when compared with traditional materials.

Production of advanced materials is more knowledge and technology intensive and less capital and labor intensive than production of conventional commodities. Although they are less amenable to economies of scale, advanced materials can be used to reduce total systems costs. A much wider range of scientific expertise is required to achieve a desired product, and after the material is formulated, designers, engineers, and assemblers must work with material scientists to ensure product reliability at minimum cost.

Advanced materials can reduce overall production cost, improve performance, and provide a competitive edge in many products. For example, producing automotive connecting rods by powder metallurgy forging is about 10% more economical than forging them conventionally. Although the mold needed for powder metallurgy costs more than a conventional forging tool, the new method requires less labor, yields a more precisely shaped rod, and less material is lost in finishing.





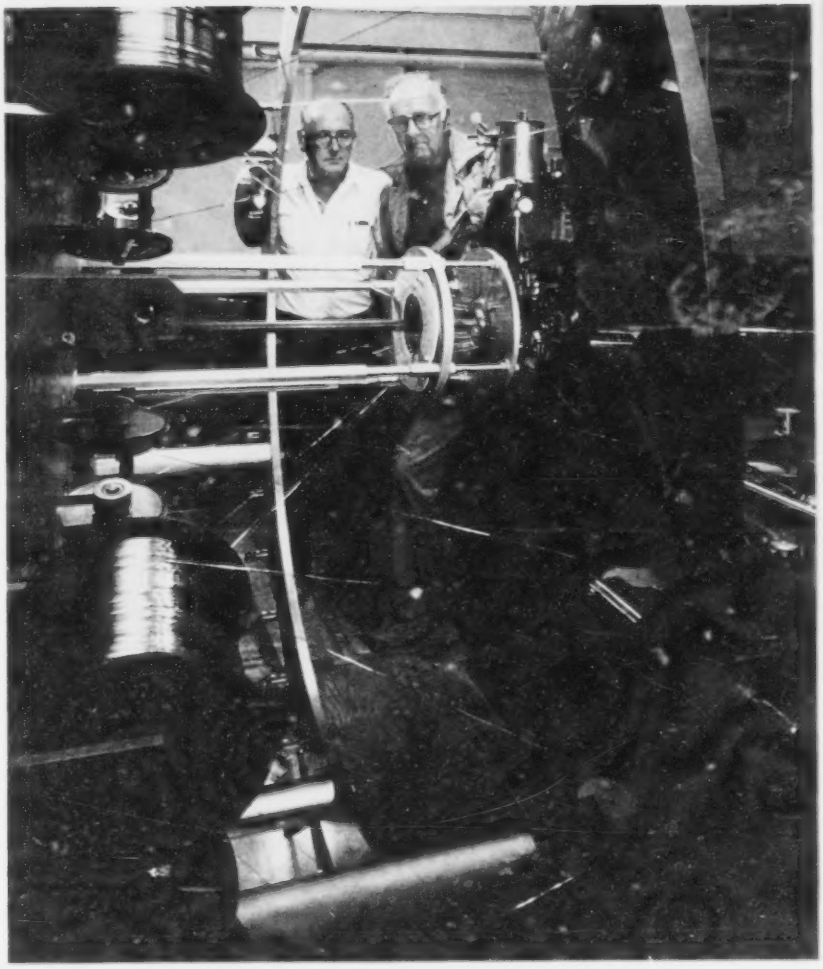


In the past several years, there has been a shift not only in the thrust of U.S. technology, but also in the debate about national mineral policy. The concerns have grown from vulnerability of strategic mineral and material supplies to include productivity in the minerals industry and associated R&D priorities. There is a growing awareness in the United States and other developed countries that mineral competitiveness and industrial innovation in transportation, communication, information systems, and manufacturing depend upon development and application of new materials.

Accordingly, the industrial world is beginning to address the development of advanced materials technologies. New, innovative corporate structures, coalitions between Government and industry, cooperation among companies in sharing R&D information, innovative financing, and investment such as R&D limited partnerships are emerging, with profound implications for industrial infrastructure and Government policy.

A potential barrier to the growth of advanced materials could be the byproduct status of raw minerals used to engineer them. Many elements used in the synthesis of advanced materials are obtained wholly or in part as byproducts of the production of minerals such as aluminum, copper, lead, and zinc. Among these are gallium, germanium, indium, thallium, selenium, and tellurium. Availabilities of these elements are directly linked to production of commodity minerals. So, in a sense, the future of certain new materials will be dependent on the continued production of the more traditional commodity materials.

Although the United States has achieved a strong position in advanced materials technologies, achieving world leadership in the commercialization of these materials may be difficult. In many respects, the competitive challenges facing advanced materials are the same challenges facing the entire minerals sector of the U.S. economy.



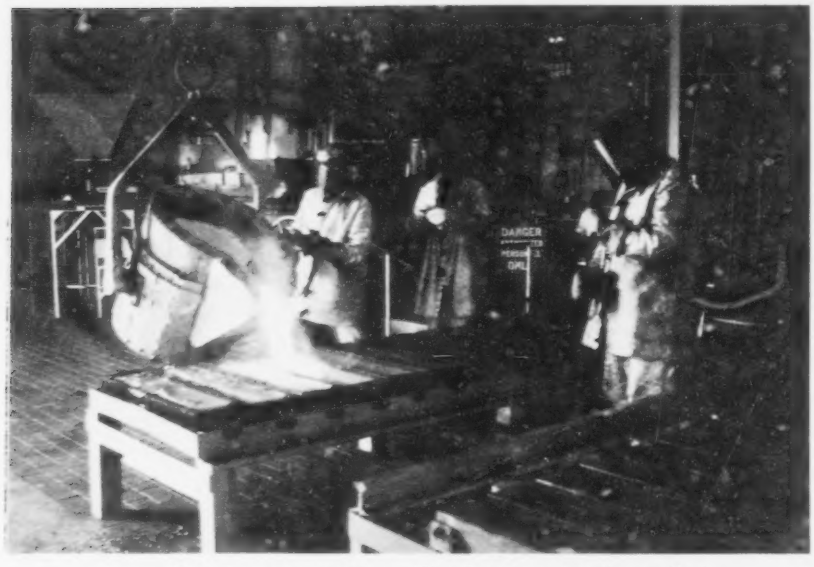
Advanced materials are essential to maintain national security and economic prosperity. The Bureau works with both advanced materials and traditional mineral products to make improved materials available to the Nation.

MINERAL ISSUES—1989

Mineral Issues analyzes selected domestic mineral industry issues, their implications for public and private policymaking, and the capabilities of the Federal Government for resolving the problems or issues involved. The current report addresses the following issues.

International competitiveness of U.S. copper production, 1981–87. Many factors have influenced the competitive position of the U.S. copper industry in relation to world industry between 1981 and 1987. Oversupply of copper and low metals prices have caused producers throughout the world to institute rationalizations and cost-reduction measures in an attempt to improve competitive position and profitability. Many operations made changes in mine plans. Stripping ratios were lowered. Pit slopes were increased. Mill feed grades were raised. Labor requirements were reduced and wage rates were cut. Smelting and refining charges were negotiated downward. Technological improvements were implemented. Some high-cost operations were unable to compete in the world market and were closed. These factors resulted in some significant copper production-cost reductions in many countries.

However, other factors beyond the control of mine operators also influenced production costs. Inflation, exchange rates, government policies, and byproduct prices offset or enhanced cost-reduction measures. This offset or enhancement resulted in a reordering of the relative positions of average production cost of the major copper-producing countries in the 1981–87 period. Zambian mines, for example, improved their competitive ranking. Canadian and U.S. mines, despite implementing many cost-reduction measures, saw little change in their relative rankings through 1987 but improved their ability to compete on the world market.



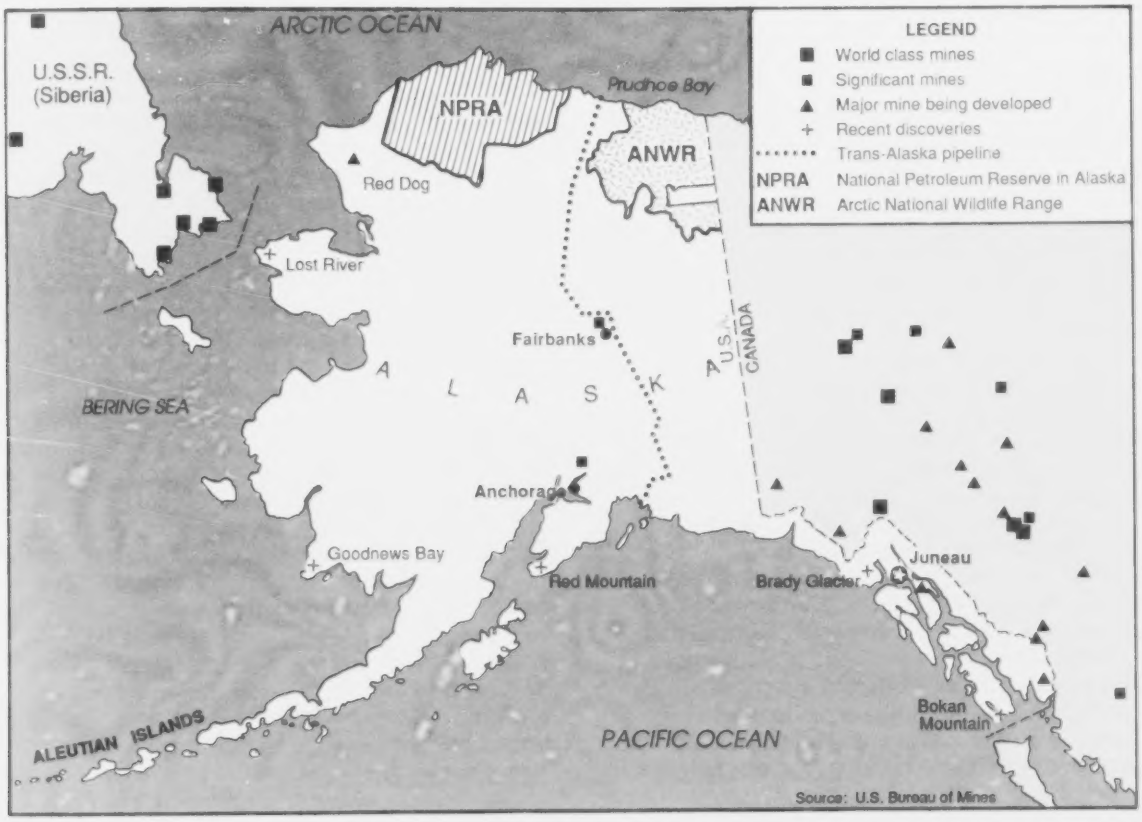
Pouring copper pigs. The Bureau recently studied the relative competitiveness of the U.S. copper industry.

Two economic factors that have had a large impact on competitiveness are foreign exchange rates (when coupled with inflation) and world market prices for byproducts. For U.S. producers that must compete with foreign producers, these economic factors can be as important as technical factors, such as stripping ratios, in determining market share. For example, the weakening of the U.S. dollar exchange rate in 1986 and 1987 in relation to other major copper-producing countries improved competitiveness of the U.S. industry significantly, even if other factors were held constant. In addition, the increase in byproduct prices between 1987 and 1988 has significantly lowered the cost of production for many mines and once again improved the competitive position of several countries, including the United States.

A major long-term issue for U.S. producers is the extent to which cost-reduction measures can be sustained. Wider adoption of efficient technology and rationalization in the industry are continuing. The industry survived the last economic downturn but with fewer mines than in 1981. The industry is expected to exceed production levels of 1981 within the next 2 years. It is leaner and more productive than ever before. Despite many factors beyond its control, the U.S. copper industry is well positioned for weathering future copper market cycles as a viable portion of the world copper industry.

Future technological needs of the domestic mining industry. The domestic nonfuel minerals industry has experienced a serious erosion of its competitive position in the world minerals markets. The Bureau has estimated that metal mines must boost productivity by 40% to 50% over the next 10 years if they are to compete with foreign operations. Mining companies must adopt innovative technology to substantially lower the cost of recovering minerals without compromising the environment and without jeopardizing miner safety.

To survive, domestic companies must embrace new technology, but the process must be relentless—it cannot be a one-time fix. They must remain on the leading edge of technology to keep ahead of their competitors. Although



Realization of Alaska's mineral potential has lagged that of neighboring Canada and Siberia, which have similar mineralization but fewer constraints.

many domestic companies have adopted a positive attitude toward new methods, the financial difficulties experienced by the mining industry over the last 6 years preclude many mining companies from researching new technology. Therefore the Bureau is focusing more resources on developing technology that can reduce mining costs and achieve a significant increase in productivity.

Necessary steps for realizing Alaska's minerals potential. Alaska has a long history of mining and minerals production and owes much of its economic development to the mining industry. Political, economic, and technical constraints, however, have limited the growth of the Alaskan mining industry in recent years to a point where it contributes far less than its potential to the Nation's economy. Significant undeveloped resources of platinum, chromium, cobalt, nickel and tin—all critical materials for which the United States has a high import reliance—occur in Alaska. Developing these mineral resources could have many benefits. Alaskan minerals development could allow the United States to become more self-sufficient in many of these mineral commodities, possibly reducing the U.S. trade deficit by $1–$2 billion by 2020. Pacific rim consumers such as Japan, Korea, Taiwan, and China provide ideal markets for Alaskan minerals. Coal from Alaska already is being exported to Korea and export of zinc is expected to begin in 1990.

Moreover, mineral development would help diversify Alaska's economy, making it less dependent on oil and gas revenues, which are expected to decrease in the next few years. Alaska's mineral resources can provide impetus to the Alaskan and National economy through increased employment, investment, and diversification. Historically, mining has been responsible for development of much of Alaska's infrastructure, which in turn has allowed greater access to and development of resources such as tourism and forestry. Eventually, the raw minerals produced in Alaska could be used to support secondary industries. Manufacturing appears to be increasingly feasible in Alaska as energy costs are relatively low, wages are achieving parity with the lower 48 States, and transportation costs are becoming more competitive.

The mineral potential of China. After a quarter of a century of closed-door policy, the "bamboo curtain" lifted and China opened to the external world in the 1970's. Foreign economic interest in China grew markedly as the Government encouraged importation of foreign technology and capital to modernize the country's industry. The overall objective was to quadruple the country's gross national product between 1980 and 2000. With more than 1 billion people—representing a quarter of the world's population—achieving this goal is a formidable task.

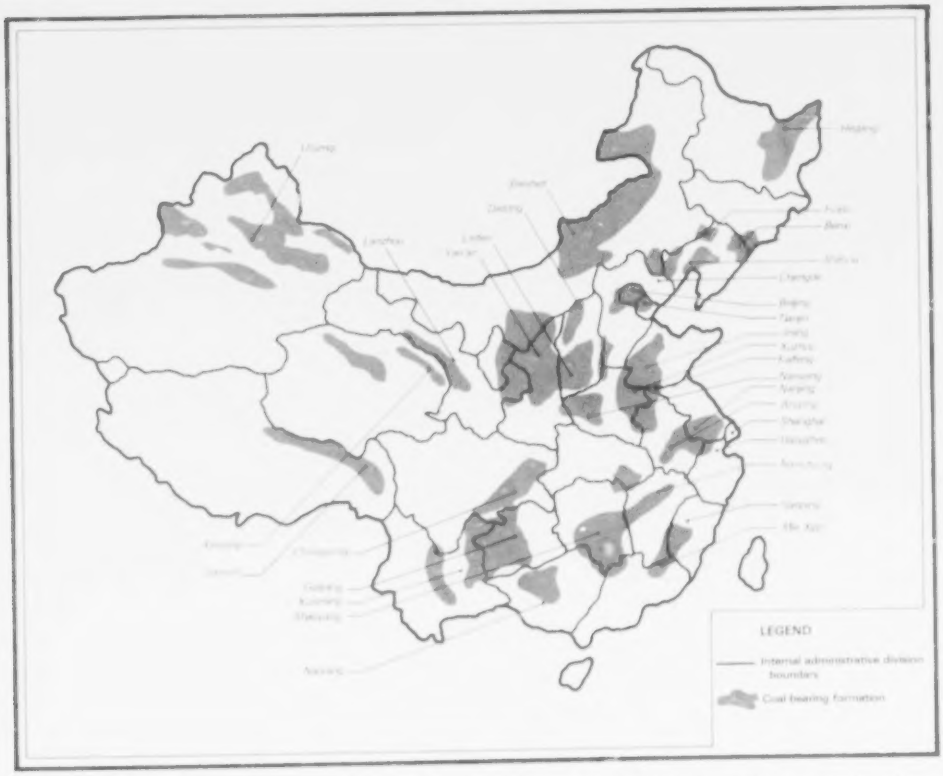
To help finance the country's modernization program, China sought initially to increase exports of foodstuffs, textiles, and light industrial goods. At the same time, China became a major world supplier of industrial minerals, shipping significant quantities of antimony, barite, bauxite, fluorspar, graphite, magnesite, petroleum refinery products, lanthanides (rare earths), salt, talc, tin, tungsten, and vanadium. These export earnings were insufficient to cover the cost of importing equipment and technology, however. In a sharp turnabout to past practice, the country opened further by permitting Sino-foreign joint ventures as well as foreign wholly owned ventures in China, especially for capital-intensive projects and high-technology manufacturing in which China lacked capability.

China possesses some of the world's richest resources of coal and a number of industrial minerals, and to a lesser extent resources of many metallic ores, petroleum, and natural gas. Quantitative data on the extent of China's mineral resources are not generally available, but the pace of development of its production capability for minerals and metals has been rapid. Within the span of the last four decades, China has emerged as a ranking world producer of antimony, barite, bauxite, cement, coal, ferroalloys, fluorspar, graphite, magnesite, lanthanides, salt, steel, talc, tin, tungsten, and vanadium—indicating a large resource base. Furthermore, it has the latent potential to be a major producer of aluminum, beryllium, columbium, lithium, magnesium, nickel, tantalum, and titanium.

The Chinese Government's industrial focus has been to obtain up-to-date technology for processing and fabrication. This is particularly true in the manufacture of various steel products where imports currently amount to $6 billion annually. During the next two decades, China is expected to continue as a net importer of certain metals such as steel and copper and to continue its traditional exports of various industrial minerals as well as antimony, lanthanides, and tungsten. China's ultimate goal is to be like the developed nations of the Far East in exporting value-added manufacture rather than basic raw minerals.

The United States is a major trading partner of China, but overall Chinese mineral exports to the United States have little impact on U.S. producers except in isolated instances such as tungsten, potassium permanganate, and textiles. As for lanthanides and talc, China's shipments are in competition with U.S. exports of these commodities. China's exports of coal are expected to grow and to capture a greater share of the market in the Far East. External shipments of Chinese coal may compete with Alaskan and other U.S. coal for markets in nations of the Western Pacific rim.

Main blast furnace, Baoshan iron and steel complex, near Shanghai, China.



A recent Bureau study assessed the minerals potential of China. Upper map shows distribution of minerals within China; lower map shows coal resources.

Federal regulation of the lead industry. The domestic lead industry, as much as any industry in the United States, has been affected by regulations to protect the environment and worker health and safety. Lead is recognized as one of the most toxic elements if ingested. As a result, in the last 20 years, the lead industry has lost two major markets in house paints and as a gasoline additive. However, current uses of lead in the transportation and electrical industries, because of their low susceptibility to substitution, are likely to continue to grow. Lead in storage batteries, including electrical and communication uses, is the largest remaining market, accounting for over 75% of demand. The primary lead smelting industry, which produces lead from ore concentrates, and the secondary lead smelting industry, which predominately recycles spent motor vehicle batteries, have been seriously affected by these restrictions and subsequent loss of markets.

The Bureau quantified the costs to the primary and secondary lead smelting industries of current and contemplated regulations (OFR 55–88). Primary lead smelting operations could be forced to close because they can not comply with current regulations for lead and sulfur dioxide emissions. For those that remain in operation, a shift in technology will be required to insure that all current regulatory standards will be met. If regulations become more stringent, as contemplated, the entire primary lead smelting industry could cease to operate. The secondary industry can meet present environmental and health and safety regulations with the installation of improved ventilation systems. However, if the more stringent regulations are imposed, much of the secondary lead industry could also cease to exist. The total loss of the secondary industry would mean that the capability for recycling spent motor vehicle batteries, a hazardous waste material, would be lost.

The primary lead industry could comply with all existing regulations with the shift to and installation of new smelting technology not currently being employed. Capital expenditures as high as $400 million would be required for the installation of this new technology. However, the estimated long-term lead selling price (generally less than 30 cents per pound in recent years) may not justify the risk of this investment. Hence, the primary industry may not be willing to expend large amounts of capital without assurance of regulatory stability and possible guaranteed financial considerations.

Although lead is a toxic element to health and to the environment, it is essential for many applications for which no economic substitute exists, particularly for automotive batteries. Projections are that U.S. consumption of lead will not decrease in the near future. The production and recycling of lead in the United States needs to be regulated to protect worker health and safety and restrict release of lead to the environment within a framework that will allow this critical base industry to exist. The lead industry and Government regulators must define a mechanism that will realistically address this issue.

Distribution of lead smelters and refineries in the 1980's.

Health, safety, and economic issues of diesel engine use in underground coal mines. Diesel engines used to power equipment in underground mining operations have many advantages over their electrically powered counterparts. The increased mobility and flexibility of diesel vehicles offers opportunities for increasing productivity. Diesel-powered vehicles are used in almost all underground noncoal mines in the United States, and they are being introduced slowly into underground coal mines. However, diesel power may not be suitable for all underground mining applications because of mine design or because of the health and safety concerns. Diesel equipment introduces some potential safety hazards into the mine environment, particularly the risk of fires involving diesel fuel and hydraulic fluid. However, it is generally believed that diesel equipment is safer than the electric-powered alternative.

A major reason for the slow adoption of diesel power in underground coal mines is the concern for the effect of exposure to mixtures of coal dust and diesel exhaust emissions on the health of miners. This concern about health effects now centers on the potential carcinogenicity of diesel particulate matter (DPM) emitted from the engine. Recent inhalation studies with animals have shown that lung cancers developed in laboratory rats when the animals were exposed to 3.5 mg/m^3 or more of DPM for at least 30 months. A recent epidemiological study of mortality among U.S. railroad workers found that exposure to DPM slightly increased the risk of lung cancer mortality. The United Mine Workers of America has opposed the use of diesel engines in underground coal mines because of these potential health concerns. The health and safety aspects of diesel use have caused concern at the State and Federal levels as well. West Virginia and Ohio have statutes that prohibit use of diesels in underground coal mines.

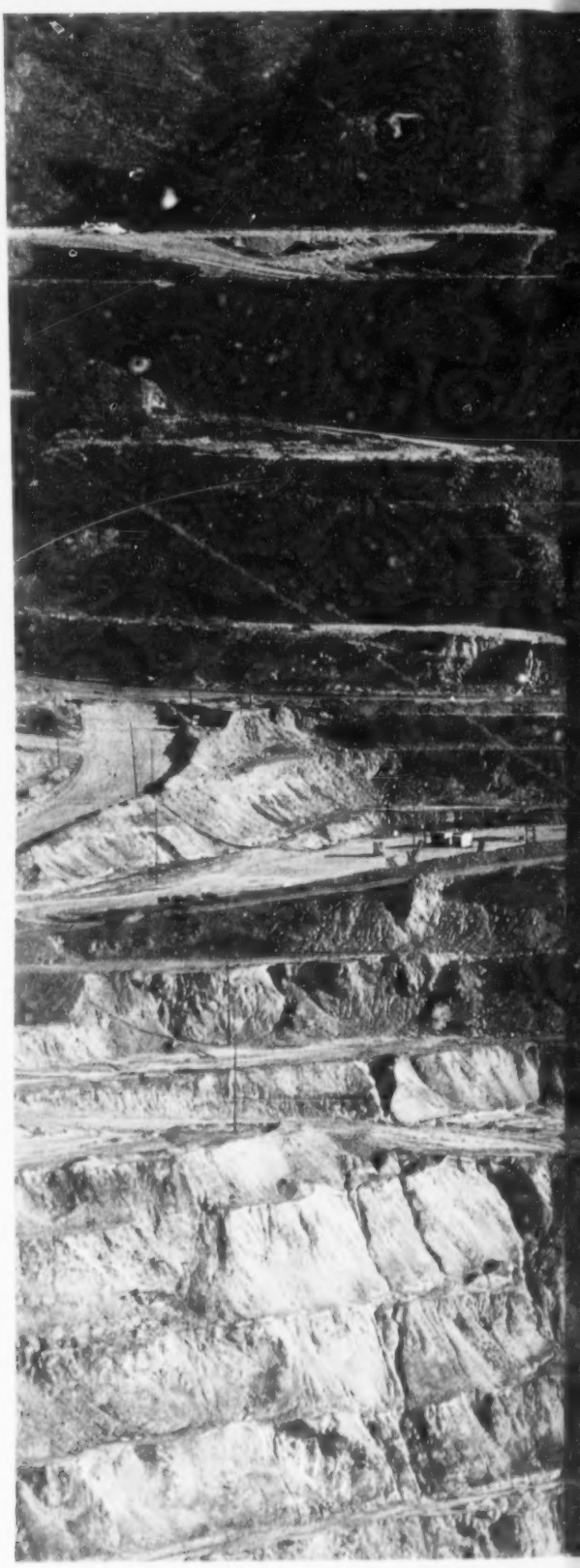
The Bureau has a research program with a goal to minimize or eliminate health and safety hazards of diesels. The Mine Safety and Health Administration (MSHA) is the Federal agency responsible for regulation of health and safety in mines. MSHA has formed an advisory committee that has made recommendations that could lead to new regulations for the use of diesels in underground mines. Such new regulations could have a strong impact on the extent of diesel use in mines and could affect productivity and competitiveness as well as the health and safety of mine workers.

Diesel-powered front-end loader. The Bureau is conducting research into ways to increase the safety of using diesel equipment underground.

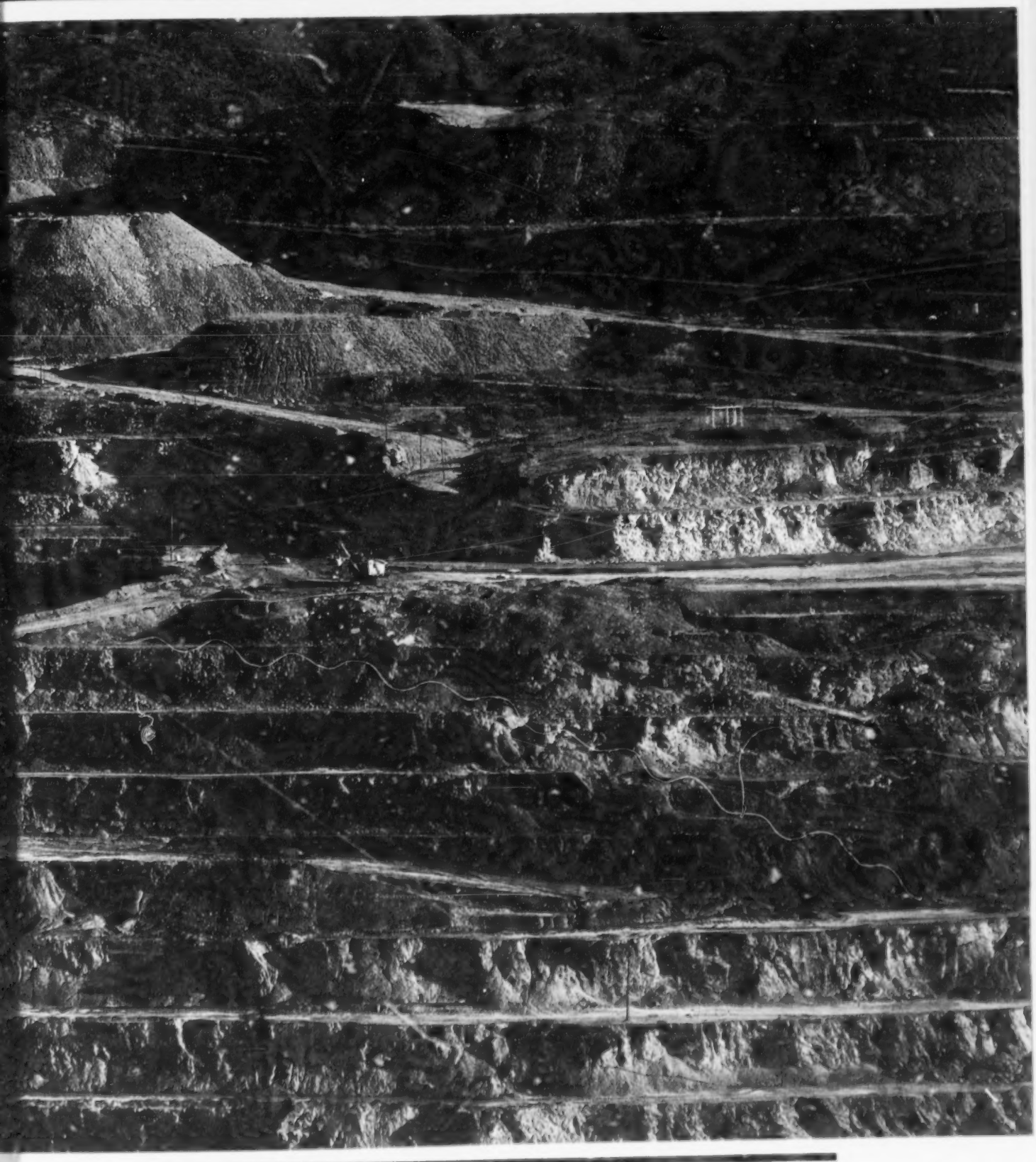
Mining waste regulation. Solid waste management is a major national issue. Media coverage of medical wastes on the Nation's seashores and municipal waste barges plying the oceans with no friendly port have raised the issue to national prominence. Mining and beneficiation wastes represent nearly 40% of the Nation's total solid waste with approximately 2.4 billion metric tons generated annually. Unlike municipal and industrial wastes, mining and beneficiation wastes tend to be generated in large volumes at a relatively few, generally remote sites. Thus problems and issues associated with mining and beneficiation wastes are very different from those related with municipal and industrial wastes.

Gases emitted to the atmosphere and liquids discharged to the Nation's waterways long have been controlled at the Federal level under the Clean Air Act and the Clean Water Act. The Resource Conservation and Recovery Act of 1976 addresses the regulation of industrial and municipal solid wastes, but Federal legislators and administrators have yet to develop a mechanism to manage mine waste.

Nearly half of the mine wastes are mining overburden and other mined material that does not warrant processing. In addition, they are not as dangerous as those types of wastes typically managed as hazardous wastes. Nonhazardous mine waste exists in such quantities and is sufficiently different from other kinds of industrial waste as to justify a separate set of regulations and administration. Nonetheless, improper handling of mining and minerals processing wastes may result in harm to human health and the environment. The Federal Government is faced with a situation where its existing authorities and regulations do not match the need for regulation. In many instances the States have filled the void with flexible regulatory programs that account for site-specific conditions such as climate, geology, characteristics of the waste, hydrology, and soil chemistry. A Federal program that recognizes the capability of the States to regulate and that accounts for the uniqueness of mine waste is needed.



The Bureau has worked closely with EPA to assist in the development of regulations that recognize the difference between mine waste and hazardous waste.



Outreach Activities of the U.S. Bureau of Mines

Office of Public Information

The Office of Public Information disseminates information on a wide variety of subjects relating to minerals and Bureau programs and objectives to a wide range of publics, from school children to Federal officials, reporters, scientists, economists, policy analysts, engineers, and representatives of the mineral industry. Many of the information materials generated by the Bureau traditionally have been highly technical. A primary goal of the Office of Public Information is to produce materials presenting the work of the Bureau in nontechnical terms for more general audiences. To this end, the office produced a booklet in 1988 entitled *U.S. Bureau of Mines: The Minerals Source*, which provides a brief, illustrated overview of the Bureau and its programs written in clear language. The office also prepares briefer information packages and fact sheets. These and other Bureau publications are available from the Office of Public Information, Mail Stop 1040, U.S. Bureau of Mines, 2401 E Street, NW., Washington, DC 20241-0001.

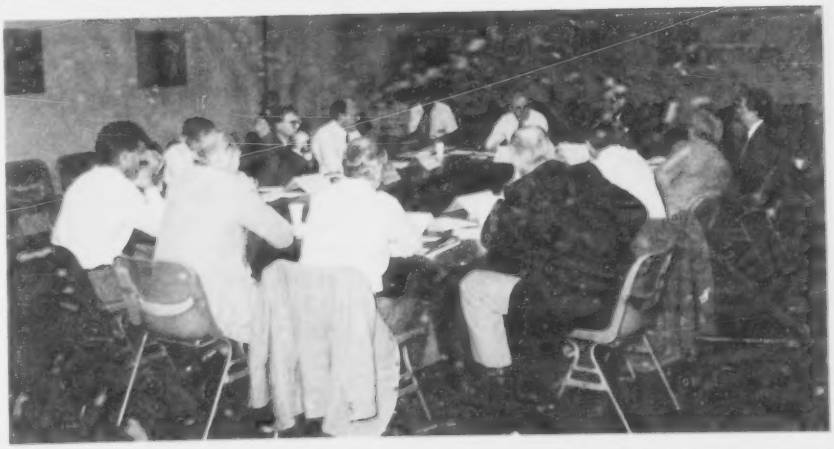
Minerals Information Office

As part of its outreach program, the Bureau joined with the U.S. Geological Survey (USGS) to establish a Minerals Information Office at the Department of the Interior Building in Washington, DC, and at USGS field offices in Spokane, WA, Reno, NV, and Tucson, AZ. The offices will be staffed by professionals who can interpret published information on the location, extent, and character of mineral resources; explain published information and statistics on mineral resources; contact commodity and area specialists; and retrieve information from existing computerized mineral data bases.

Office of Technology Transfer

The Office of Technology Transfer brings the results of Bureau research and information programs to the attention of the minerals industry. The philosophy behind technology transfer is that breakthroughs in mineral research are useless unless they are adopted by industry. The office's outreach activities include holding seminars and open industry briefings and providing exhibits at major national mineral industry conventions. In 1988, 40 such activities were conducted. The office is responsible for the licensing of patented technology evolving from Bureau research. The office also publishes *Technology News* and makes available a series of technology transfer films. Information on the Bureau's technology transfer program and licensing of Bureau patents is available from the Chief, Office of Technology Transfer, Mail Stop 6201, U.S. Bureau of Mines, 2401 E Street, NW., Washington, DC 20241-0001.

Technology Transfer Office in Anchorage.—In January 1988 a technology transfer office was opened in Anchorage, AK. The office is helping Alaska's mining industry identify and adopt new mining, mineral processing, reclamation, and waste treatment technologies. Besides channeling technical information from Bureau research, information, and analysis programs, the office provides a single location where varied mineral interests can locate technical assistance and information. The office also relays information on the unique character of Alaskan mining and mineral processing problems to other Bureau offices for possible investigation.



The Bureau provides information exhibits for mining and mineral conventions (top photo, this page), holds open industry briefings and seminars (middle photo), and works to encourage mining and mineral awareness in cooperation with a variety of school programs across the Nation (at right, and facing page).

Research

Mining Technology

Innovative Mining Methods. New ways to mine and process ore are a major research focus of the U.S. Bureau of Mines. As discussed in "Perspectives," this research contains a major component on in situ leach mining. In 1988, the Bureau leached cores from several copper ore deposits under conditions simulating those of leaching operations. Test results allowed researchers to determine the reactions occurring during leaching. Knowledge of these reactions permits engineers to predict copper recoveries. Engineers can also learn which waste elements the solution will dissolve with the copper and the amount of solution used during leaching. From such information, engineers can determine if it is possible to profitably leach mine a deposit.

Engineers must know how a leaching solution moves through rock to evaluate its effectiveness. The Bureau modeled the influence of cracks and other geologic features on solution movement. The model predicts leaching solution movements between vertical injection and recovery wells drilled into a deposit. It also models solution movement in ore rubble leached in old underground mine workings. Researchers developed the model specifically for the copper deposits prevalent in the southwestern United States. Researchers also worked with mining industry engineers to determine how to more uniformly distribute the solution throughout the rock.

Operators also need methods to monitor solution movement during in situ leach mining. If operators know that solutions are not reaching part of a deposit, they can alter the pattern of wells distributing the solutions. If the solutions begin to migrate away from the desired recovery zone, operators can recover them. Bureau researchers developed a technique of rapidly and easily locating rock filled with leaching solution. The method uses desk-top computers to analyze sound waves passed through the ground.

Through a contract, the Bureau is preparing an in situ copper leach mine design manual to provide engineers with technical and economic data necessary to design an in situ leach mining operation. The manual concentrates on deposits in which the copper occurs in an oxide form. Oxide deposits, the most likely candidates for future in situ leaching operations, are common to the southwestern United States. Because technical and economic data show in situ leach mining of these deposits should be commercially viable, the Bureau initiated a 5-year, large-scale field experiment. The experiment will improve the understanding of engineering parameters and environmental safeguards necessary to make the method commercially attractive.

The Bureau has developed technology for mechanically cutting and fragmenting hard rock that can be applied by industry to development of highly automated rock excavation systems for underground mining. The studies focused on improving the "ripper" miner concept developed by the Bureau. The concept features a cutting machine with one large bit to excavate rock in underground mine openings.

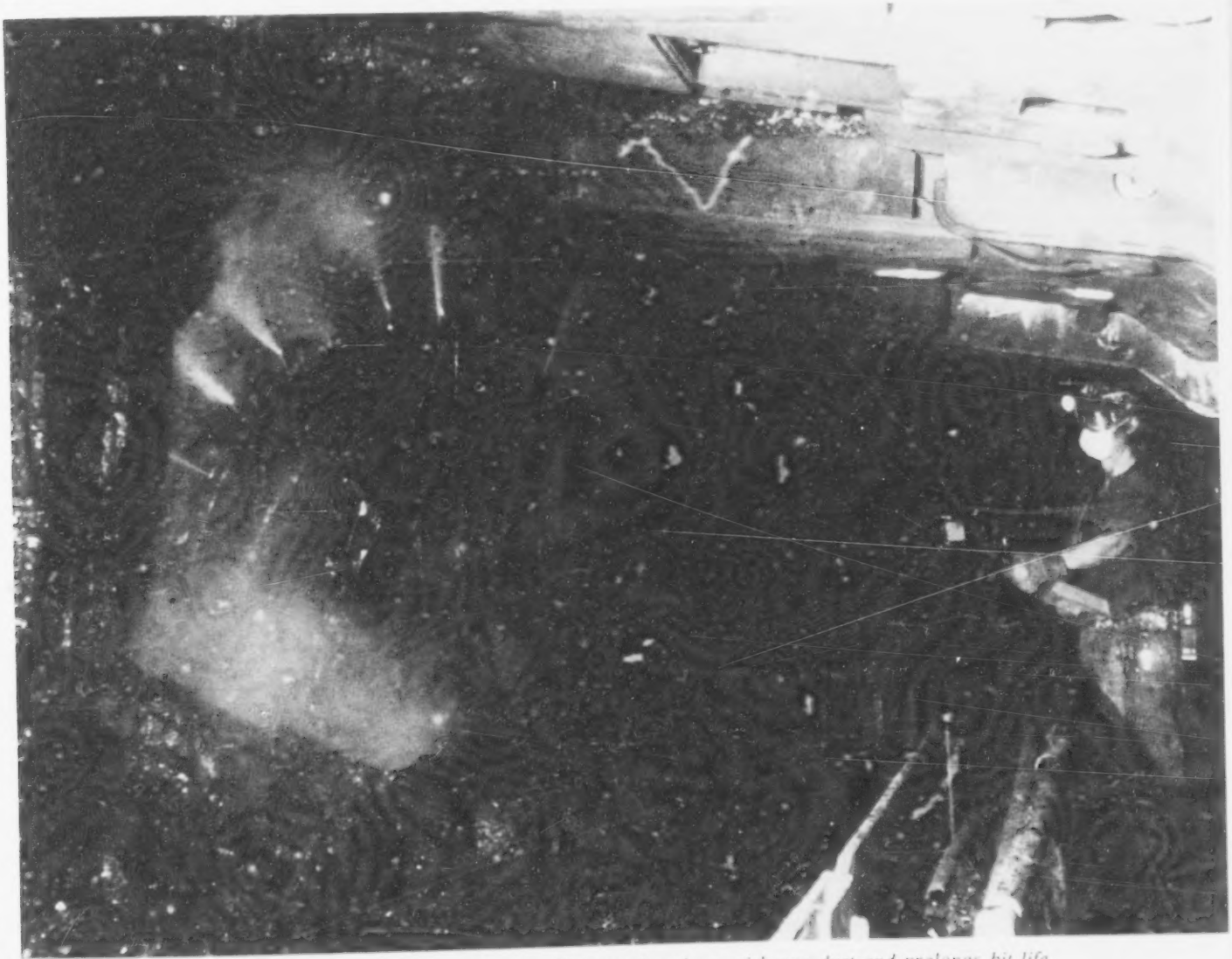
New bit designs developed for presently available soft-rock cutting systems included a double-acting drag bit and a concave bit. Both bits exploit tensile rather than compressive forces in their cutting action. This allows the machine to cut with less force or energy because rock splits or cuts easier than it crushes. Present bits waste energy by crushing rather than cutting much of the rock contacting the bit. In tests on limestone, the concave bit cut with 30% less energy than did a conventional drag bit.

The Bureau concluded its study of another innovative mining technology—drilling with water jets that contain abrasives. The drill has no expensive bit that operators must frequently change or that can wear out. In the method, pressurized water jets carrying common sand-blasting abrasives erode a hole in rock. The drill is basically a nozzle that focuses the water jet and points it in the desired drilling direction. The abrasive jet drill was used successfully to drill holes in a variety of hard rocks with low water pressure. Operators can "ream" a larger diameter zone in a hole where, for instance, blasting engineers may wish to place more explosives. Operators can easily drill loose rock, which is very difficult to drill with current drills. Slots and overlapping holes are also easy to drill with the abrasive jet.

A longwall shearer can mine coal faster than any other machine now used in underground coal mines. Metal bits, located on the surface of rotating drums, break the coal and remove it from faces that are typically 600 to 700 feet long. Bureau research is looking at ways to further improve shearer efficiency. One technique uses high-pressure water jets directed from nozzles located in front of each bit. At a pressure of about 6,000 psi, the solid stream of water can penetrate and remove the broken coal and rock that forms in front of the bit allowing the bit to cut more efficiently.

The water-jet-assisted cutting system has been successfully installed on a longwall shearer. Work is continuing to find ways to increase the pressure of the water jet where it impacts the coal. One study has shown that this impact pressure can be increased as much as 400% if flow turbulence is reduced before the stream reaches the nozzles. Laboratory studies using a single-bit linear cutting apparatus are being conducted to determine how much forces on the cutting bit can be decreased by using water-jet assist. In addition to its effect on cutting efficiency, water-jet-assisted cutting has reduced airborne dust on a mining section 80% and has prolonged bit life.

The Bureau examined fundamental technology for breaking rock with microwaves. When rock is radiated with a microwave beam, the energy concentrated inside the rock and converts to heat. The hot spot inside the rock expands, causing the rock to crack. Researchers broke several rock types with this technique. They also dried coal and minerals with microwave technology. Microwave heating also appears promising for separating the desired mineral from a complex mixture of minerals—a step in mineral processing.



Not only does water-jet-assisted cutting improve shearer efficiency, it reduces airborne dust and prolongs bit life.

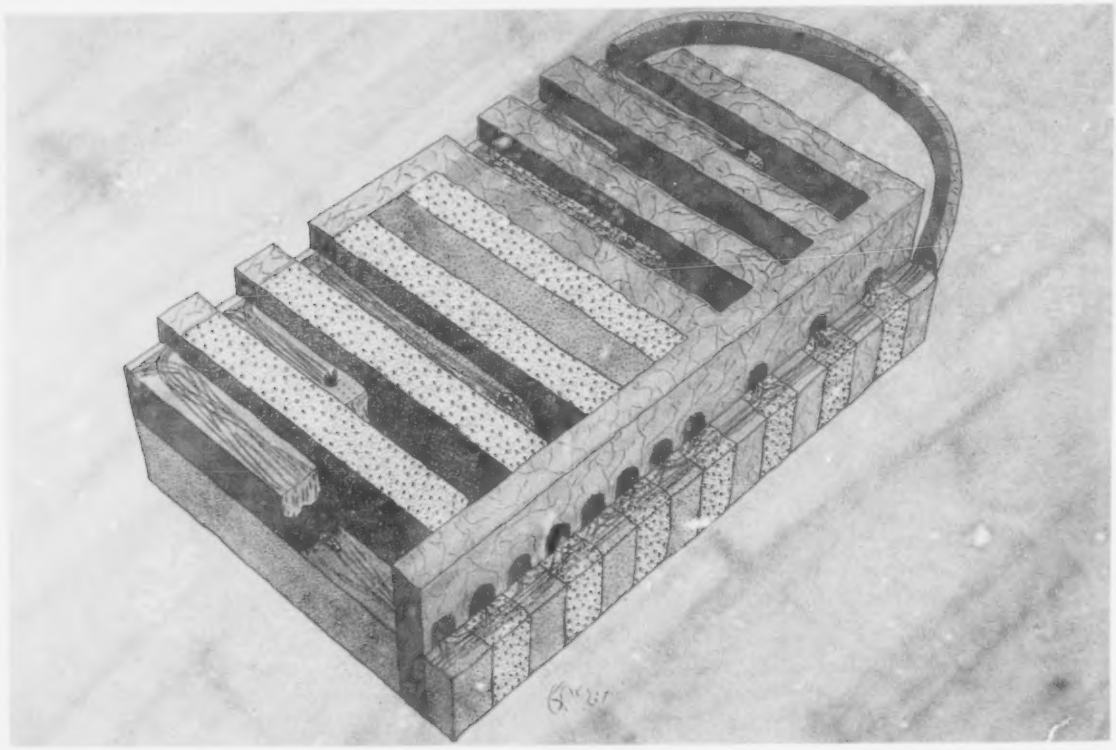
Advances in Conventional Mining Technology. As companies mine deeper and lower grade deposits, they need to improve mining efficiency. Some of the preceding innovative mining methods offer the best long-range chance for profitable mining. Until those methods become readily available, however, many companies must improve mining efficiency with present methods.

Underground mines have shifted toward high-volume methods of extracting and hauling ore. The equipment used in these methods draws heavily from open-pit operations and the construction industry. Companies believe this equipment will increase productivity, improve safety, and decrease mining costs. Successful adaptation of such methods requires totally new mining sequences and configurations. The Bureau, along with the mining industry and universities, developed fundamental design technology necessary to accommodate the new equipment. A cooperative study at the Carr Fork Mine in Utah is a good example of the application of this technology. The study showed that the Bureau design procedures were suitable for determining dimensions of underground openings in advance of actual mining. It also showed that miners could safely double the width of the mine openings and increase primary extraction by nearly 100%.

Researchers completed a similar study at the Homestake Mine in Lead, SD. They examined the effects of geology and increasing depth on underground opening dimensions and support. The results confirmed a company decision to shift more of its production capacity to a large-volume mining method. With this method, miners produced 92% more ore per hour than they did with previous methods.

Companies normally mine deep, massive ore bodies by excavating large rooms. Miners must leave much of the ore in these rooms as pillars to support the mine roof. This practice not only wastes resources left in the pillars, it often does not provide the support intended to prevent long-term subsidence. Some companies filled underground openings to remedy problems in subsidence; these companies are now realizing that backfilling also allows them to recover more of the resource.

The Bureau investigated new methods of filling mines to allow profitable extraction of the total resource while preventing subsidence. In one study, researchers made fill material from fine minerals processing waste rock (tailings). The Bureau developed technology for dewatering and pumping this pastelike material to underground openings. This dewatered fill is more sta-



Bureau studies permit mining companies to expand applications of backfilling technology. This allows them to improve mine support and to recover a higher percentage of the ore in a mine.

ble than tailings pumped in their normal slurry consistency. Using the tailings as fill also solves a surface waste disposal problem.

Because companies may add cement to fill for strength, the Bureau studied the influence of cement additives. Cement and fine-grained tailings mixtures with additives behave different from construction cement with the same additives. The Bureau provided technology to enable mine engineers to determine the best backfilling recipe at reasonable costs.

Some mines are switching to a relatively new support technique called cable bolting. This support system uses flexible bolts made from twisted strands of steel cable that are cemented into slender drillholes. The Bureau improved this technology so that miners could better support mine roof rock while lowering mining costs. The Bureau evaluated samples of various types of cables, cements, and insertion tubes to determine their influences on the ability of a cable bolt to support rock. Researchers found that cable bolts installed with very wet cement mixtures do not hold as well as ones installed with drier mixtures. Mining companies often mix cement with too much water so that it pumps easily into the cable bolt holes. The Bureau found that adding commercially available water-reducing agents to the cement improves pumping without reducing bolt strength.

The Bureau continued investigating the improved drilling performance obtained by adding small amounts of a polymer, polyethylene oxide, to the drilling fluid. The previously successful laboratory tests were extended to field scale by testing the additive in several mining operations. One field test was conducted at a taconite mine in northern Minnesota. Bits used to drill blastholes in this extremely hard rock lasted 26% longer with the additive than without it. Even more impressive is that the bits drilled 70% faster with the additive. Subsequent tests in other hard rocks have consistently yielded a doubling of the drilling rate. The additive increases bit life an average of 50%.

Blasting remains the overwhelming choice of methods to break rock in mines and quarries. Bureau researchers continued studying means to predict rock fragmentation by blasting. Currently, mine engineers must design blasts that produce the desired rock product, but have no predictive method to analyze the effectiveness of the design. The Bureau worked with Sandia National Laboratory to obtain models of the size distribution of blasted rock in quarry blasts. The models also predicted the distance that a blast would toss the fragmented rock away from its original position. The models worked well for big fragments but did not model the fine material created next to the blast hole. These models are being improved. The Bureau has developed empirical relationships between quarry blast results and key blast parameters—blast geometry, explosive type, and blast timing.

Large forces or stresses inside the Earth often create adverse conditions in mines. The forces can buckle and heave mine floors or break roof and pillar rock (sometimes violently). The damage may force a company to close entire sections of a mine. Beside the obvious safety concerns they create, these conditions severely raise mining costs. The Bureau seeks better technology for determining stress in mine rock. Knowledge of the stress allows miners to pick mining strategies that minimize damage from stress. The current methods of measuring stresses employ various gauges placed in holes drilled into the rock. These methods do not allow mining companies to measure stresses well ahead of mining or to continuously monitor stress conditions as mining progresses. The Bureau investigated two geophysical methods of measuring stress. The first uses the speed of sound waves sent through the rock to determine the stress in it. The second method measures the noise given off by a rock loaded in laboratory tests to higher stresses than it had experienced in the ground. Together these methods allow mine engineers to routinely monitor stress levels throughout mining operations.

Advanced Materials in Mining. Advanced materials development recently emerged as one of the most important high-technology industries in the United States. Improved materials and fabrication processes now being introduced should alter traditional mining practices. Their use can improve equipment performance, reduce wear and corrosion, provide better ground control systems, upgrade communications systems, reduce energy consumption, and improve ore recovery processes.

The Bureau investigated advances in materials science to determine what new materials are available and to identify their potential uses in mining. The high-temperature superconductors, for example, could revolutionize mineral processing technology. Superconducting magnets could replace chemical methods for separating valuable minerals from waste rock. Because superconductors can carry up to 250 times more current than copper wire of the same size, electric motors made of superconducting wire would be very compact. Superconducting electric motors could power mining equipment such as underground vehicles for hauling ore.

Significant advances have been made with tough plastic materials. Applications in mining include linings for buckets and trucks, bearings,

structural components for heavy equipment, ground supports, and gear wheels.

Manufacturers introduced a new generation of high-strength plastic composites in the early 1980's. These composites, reinforced by glass, carbon, or other materials, would drastically lighten any heavy mine haulage equipment constructed with them. The weight savings would dramatically increase the payload carried.

Advanced ceramics can withstand high temperatures, wear, and corrosion, thereby making them extremely useful for cutting tools, gathering arms, mechanical seals, conveyor components, and robotic equipment. With continuing development, ceramic composites could be applied in high-temperature environments, such as diesel engines, heat exchangers, and mineral processing furnaces.

Manufacturers recently developed several high-performance metal alloys. Researchers anticipate that a variety of these alloys will become important in mining, particularly in equipment subjected to much wear.

Information obtained from this investigation of advanced materials will aid researchers in the development of technology for stronger, tougher, lighter equipment for advanced mining and processing systems.

Automation and Robotics. An automated mining machine must rapidly and accurately detect the coal-noncoal interfaces of the seam; it must make essentially real-time decisions. The coal-noncoal interface can be detected only if there is a measurable contrast between one or more basic properties of the geological materials (mechanical, electrical, radioactive, seismic, elemental, etc.). These properties must be identified and measured.

It seems probable that a single sensor will not suffice for a general interface detection solution, because the geology in mines changes very rapidly; a suite of sensors will probably be needed to measure independent properties of the interface simultaneously. Onboard machine intelligence will then analyze this information and adjust the cutting head position accordingly. A key element is the application of computer-based data analysis techniques, such as adaptive signal discrimination. Although different geological conditions may require a variety of sensors, they provide the flexibility for a general solution. Application of adaptive signal discrimination to machine vibration and in-seam seismic signals is showing good preliminary results.

Two other promising techniques for coal-rock interface detection are infrared (IR) imaging

The Bureau is collecting data on in-seam seismic signals generated by mining machines to be used in developing a coal-rock interface detection system for automated mining machines.

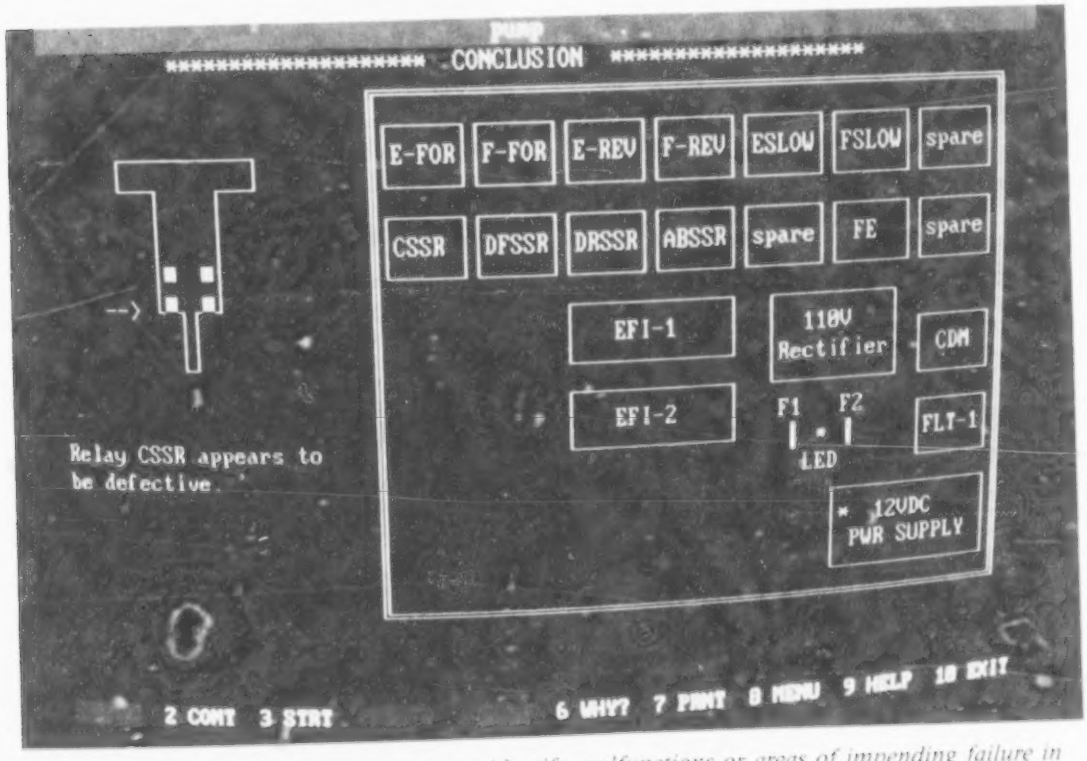
and doppler radar. High-sensitivity IR cameras can discriminate between materials of different hardness and emissivity as these materials are cut. When a cutter bit strikes a material, it creates an IR signal unique to that material. Because geological materials almost always differ in hardness and emissivity, a discrimination technique is possible.

With the doppler radar scheme, an array of small antennas synthesizes a spatial movement via electronic switching. The doppler history generated by this apparent antenna motion is digitized and stored in computer memory. The computer correlates this history with prestored templates of various coal dielectric and thickness combinations, and generates a statistical match of the various combinations. The thickness of the actual interface is the match with the highest confidence level.

Much of a mining shift can often be idle because of equipment failures. One method being explored to reduce equipment failures is the monitoring of various equipment parameters that could indicate impending failure. This advance notice of impending failure would allow corrective action during a maintenance shift. Various types of sensors are available that can measure pressure, flow, temperature, vibration, and power consumption. These sensors can be incorporated in a computer-assisted machine maintenance system that can quickly diagnose malfunctions and recommend repair procedures.

The Bureau has developed prototype hydraulic and electrical diagnostic expert systems for a continuous miner. The hydraulic expert system includes knowledge for diagnosing problems within the main and pilot circuits and also one of five functional circuits, the conveyor elevator circuit. The knowledge was coded using a commercially available expert system development shell, and was structured into three levels: a top level containing one module that determines which hydraulic circuit should undergo diagnosis; a second level with a number of modules, each dealing with the actual diagnosis of a particular hydraulic circuit, and modules for repair recommendations and procedures; third-level modules that gather all pertinent sensor information needed for accurate circuit component diagnoses at the second level.

The prototype electrical diagnostic expert system diagnoses component malfunctions in the electrical control circuit. Based on an initial set of symptoms, the system leads the user through the procedures required to quickly identify faulty control circuit components; graphical displays



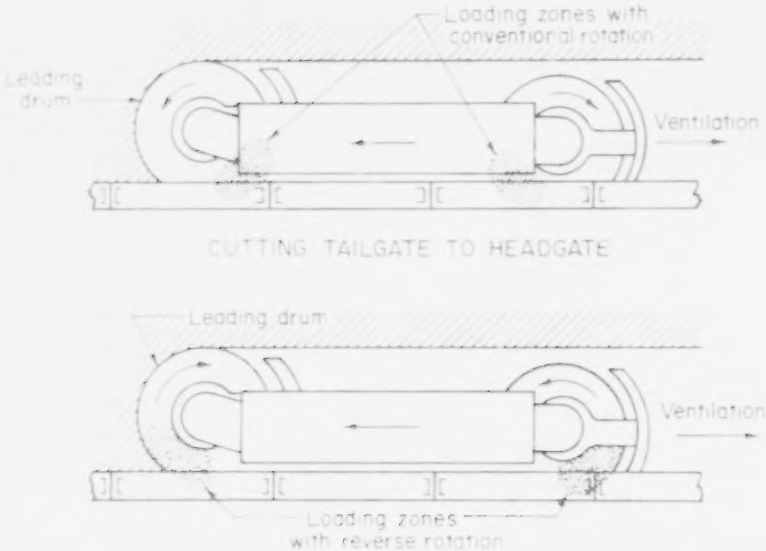
A computer-assisted diagnostic system can identify malfunctions or areas of impending failure in mining machine systems, which can reduce productivity losses caused by machine downtime.

are incorporated within the system to assist the user. The system also permits the user to access a data base of electrical components that provides information concerning specific component part numbers and availability and location of spare parts.

Health and Safety

Occupational Health. Roof-to-floor drum rotation has long been the conventional method of coal cutting. With conventional rotation, both cutting drums attempt to load under the ranging arm. As the loading aperture is only a small slit, the drums become choked, resulting in decreased tram speeds. With reverse drum rotation, the loading zones are changed. The leading drum loads out of the bottom leading quadrant, while the trailing drum loads through the cowl. In both cases, the cross section of the area through which the coal passes is substantially increased.

Three test sites were chosen for evaluation of reverse drum rotation under a wide variety of coal seam conditions and face equipment. All three sites employed double-ended ranging drum shearers that cut from tail to head. From a dust control standpoint, the most significant result using reverse drum rotation, was an average 40% (15%-85% range) reduction in dust levels at the machine operator position. Downwind dust levels during the cut pass were reduced an average of 30% (0%-50% an average of 20% (0%-40% range). Rock parting present at one site allowed the impact of reverse drum rotation on the level of respirable quartz dust to be determined.



Reversing the direction of shearer drum rotation (floor to roof instead of roof to floor) can reduce dust levels and methane release.

Results indicated a 70% reduction in respirable quartz dust levels downwind of the shearer. This would be most pertinent for sections operating under more stringent dust standards because of the presence of quartz.

High levels of methane within the seam at one of the sites allowed a determination of the impact of reverse drum rotation on methane liberation during mining. Results indicated a 22% reduction in gas levels, probably because of the increased product size; less exposed surface area generally results in less release of the methane trapped within the mined coal.

Reverse rotation reduces the proportion of fines in the product, with increased throughput at the preparation plant. Screen analysis of samples showed an average 18% decrease in coal fines. Tram speed (production rate) while cutting increased by an average of 13%. However, it would appear that reverse drum rotation is only suitable for medium and thin seams. A shearer can usually be modified to reverse rotation at a minimal cost. Problems with the traction units and machine covers are usually related to rock problems encountered on the tailgate end of the shearer.

Stringent respirable dust standards of less than 2 mg/m^3 when coal mine dust contains more than 5% quartz currently affect about 31% of underground coal mining sections, especially those with continuous mining operations w[illegible]re auger type continuous miners pose unique ventilation and dust control problems. To protect face workers from the dust, the end of the brattice is usually maintained close to the face, but it is retracted as the machine cuts toward the exhaust side, to allow the machine to complete its cut. Sometimes the end of brattice stays too far from the face. Improper extension of the line curtain, or poor installation of water sprays for dust control, rolls the dust back towards the operator.

A water-powered auger scrubber developed by the Bureau is an effective way of removing this dust. A tubular system draws dusty air from the "tunnel" area through three spray-equipped tubes that scrub the air, sends it through a demister, and exhausts it toward the return line curtain, using a hood with turning vanes. Hollow cone nozzles appear the most efficient in this application; the three nozzles consume about 6 gpm at 1,400 psi. More than 1,500 cfm of air moves through the system. The entire unit is mounted on the sides of the conveyor, partially above the top of the conveyor.

In an underground evaluation of the scrubber, the operator position dust reduction was 78%; the return air samples showed a 44% dust reduction. There was a dramatic improvement in

visibility over the entire face area and section personnel welcomed the scrubber installation.

The water-powered auger scrubber has many advantages. Because it is entirely water powered, it is intrinsically safe. There are no moving parts, making maintenance minimal, and no maintenance of filter panels is necessary. It can readily be retrofitted on existing machines. Capital expenditure is very low when compared to a fan-powered flooded bed scrubber system. Noise does not increase as a result of scrubber operation. It is adaptable to right- or left-hand exhaust ventilation.

The respirable dust in underground coal mines (up to 10-micrometer particles) that penetrates beyond the terminal bronchioles and deposits in the gas exchange regions of the lungs has long been known to be responsible for coal miners pneumoconiosis (black lung). More recent research suggests potential health problems related to excessive exposure to thoracic dust (up to 25-micrometer particles) that penetrates beyond the larynx and deposits primarily in the tracheobronchial region of the respiratory tract.

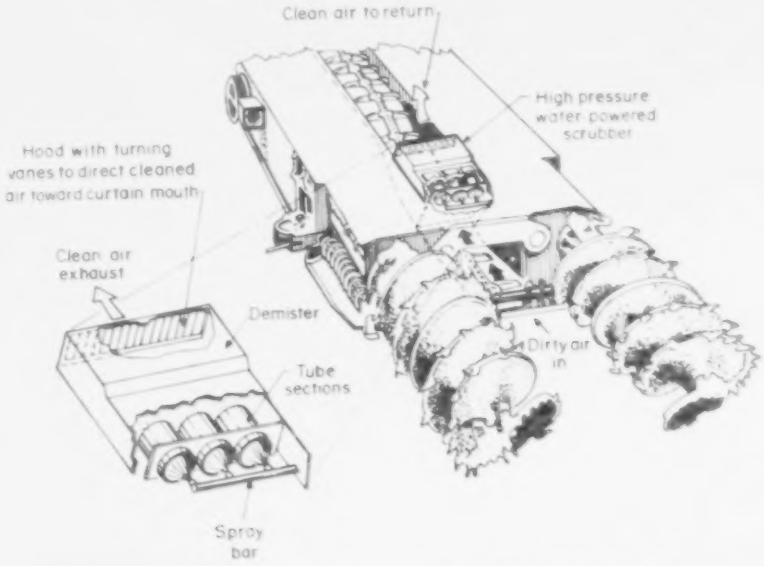
In a Bureau project to examine thoracic dust exposures on mining sections, three longwall mines were surveyed. Assuming unidirectional cutting, shearer-generated thoracic dust accounted for 70% of the total thoracic dust generated on the sections surveyed; support movement accounted for 25% of the total thoracic dust generated. Bidirectional cutting presents the worst case scenario for thoracic dust exposure because some mine personnel may be required downwind of the shearer for a significant portion of the shift. Intake, beltway, and crusher-stageloader dust accounted for only 5% of the total thoracic dust generated; however, the beltway served as a return airway at two of the mines surveyed, and the crusher discharge (onto the panel conveyor) was kept in return air. All of the mines confined the crusher and used sprays to knock down dust, which is probably very effective on the larger thoracic dust particles.

The data collected lead to some interesting comparisons between respirable and thoracic dust exposures along the longwall face. When working in intake air, a miner's thoracic dust exposure would be about twice the respirable dust exposure. In the headgate area, thoracic dust exposure would be about two to four times the respirable dust exposure. Immediately downwind of support movement or the shearer, the thoracic dust exposure would be about five to seven times the respirable dust exposure. In the tailgate area, the thoracic dust exposure would be about three to four times the respirable dust exposure.

Bureau research has identified a constant depth linear cutting concept to replace rotary drum cutting on any longwall or continuous mining machine for reduction of excessive dust generation during coal cutting. The concept has been designed to eliminate the major problems inherent in the design of rotary drum mining systems. These problems include effects of constantly varying depths of cut using fixed bit spacing, secondary dust generation by grinding of already fragmented coal, entrainment of dust generated and frictional heating of bits by high drum rotational speed, excessive bit wear caused by frictional heating, and excessive fines at the preparation plant.

The constant depth linear cutting system, based on two Bureau-developed patents, consists of a triangular-shaped drum with the bits mounted at the apexes. The drum is mounted on a spur gear at the end of an eccentric arm inside a ring gear so that as the triangular drum rotates each apex of the triangle generates a nearly square path. The proof-of-concept system being tested by the Bureau uses an eccentric arm that rotates three times for each rotation of the cutterhead, providing a 3:1 mechanical advantage.

The system will fragment coal using optimum bit spacing over 80% of the cutting path with a constant depth of cut. The concept eliminates the shallow, dust-generating portion of each rotary cut. The system breaks to a free face with no secondary fragmentation by grinding of already fragmented product. The system will have a bit velocity well below the minimum needed to prevent methane ignition and excessive



A water-powered auger scrubber can reduce dust levels and improve visibility at the face.

bit wear. This cutting system will be able to produce greater amounts of coal while keeping the dust generated well within the regulatory limit. The system will provide a product with fewer fines thus reducing coal preparation costs. Initial proof-of-concept test results compared with conventional rotary system cutting show respirable dust generation down by more than 95% and minus 1/8-inch-mesh fines down more than 80% with the new system for a given unit volume taken in a given unit time.

The constant depth linear cutting concept is a unique mining innovation designed specifically to address all aspects of health and safety while maintaining high production capability. This unique concept will improve both the return on investment and the competitive position in the world market for machine manufacturers and operators.

The Bureau has developed two interactive computer programs that enable the user to identify the effect of cutting system changes on relative dust generation and forces for continuous miner drums and longwall shearer drums. The programs simultaneously evaluate machine and coal seam parameters, and those parameters the operator can control. One or more of these parameters may be changed to determine their individual or collective effect on relative dust generation and cutting forces.

A constant-depth linear cutting system can eliminate many of the problems associated with rotary drum mining systems.

The body of data collected during the Bureau's research on coal cutting provides a broad base of knowledge. The results are available to industry in the form of a multitude of Bureau publications. The development of these two computer programs provides an easy means for people in the mining industry to find their way through the available data to extract the specific information they need.

The programs were developed to analyze the relative dust generated by a continuous mining machine or longwall shearer cutting in a coal seam containing rock band or middleman. The programs are menu driven, allowing the user to make parametric changes with a minimum of steps. The programs are written in BASIC and will run on an IBM or equivalent personal computer. The menus through which the programs operate allow the user to change parameter values, calculate dust values, and save modified data files as well as obtain printer copies of summary reports, lists of modifications, and a listing of the entire data file. Help menus provide online assistance to the user.

The programs can be used to narrow the range of cutting parameters that produce the minimum relative dust value, thereby reducing or eliminating the need for extensive and costly underground testing. After those parameters having the greatest effect on dust have been identified by using the program, they can be given the greatest amount of attention in an underground test.

A minimization routine has been developed for these programs that allows the user to specify the system parameters to be analyzed and the range over which they can vary. The program then determines the values that produce the lowest dust generation. A dynamic wear module has also been developed that determines the effect of bit wear on system performance and dust generation. This module determines the wear condition of the cutter bits over time, based on the thickness and location in the coal seam of a rock middleman.

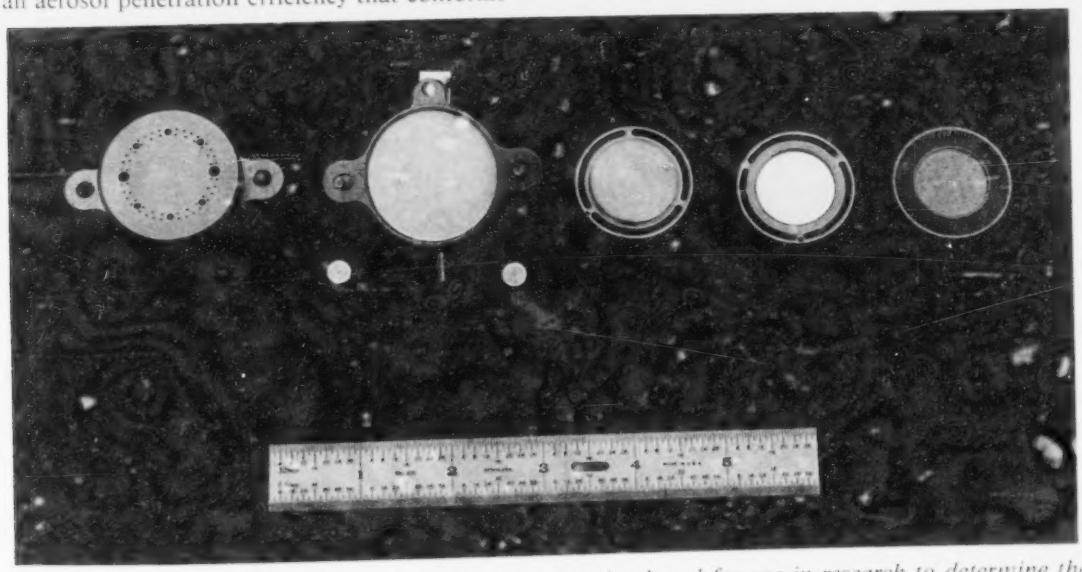
Measurements of the contribution of diesel exhaust to respirable aerosol in mine environments has become increasingly important because of research now being conducted to determine the occupational health effects resulting from exposure to diesel particulate emissions. To support these efforts, the Bureau is developing sampling methods for the measurement of diesel aerosol in underground coal mines. As part of this work, size-selective sampling is being adapted for diesel aerosol sampling. Size-

selective sampling is based on the premise that diesel and mineral dust aerosol can be physically separated by size and collected separately during sampling.

The performance criteria used in the sampler development specify three consecutive stages: (1) a preclassifier to separate the respirable part of the sample aerosol and prevent overloading, (2) a stage to separate the aerosol sample into two parts according to aerodynamic size, larger than and smaller than a specific separation size, and (3) a collector for the smaller of these two size fractions. The preclassifier can also serve to limit the sample to respirable aerosol if the effective aerosol penetration efficiency matches either the American Conference of Governmental Industrial Hygienists (ACGIH) or the British Medical Research Council (BMRC) respirable dust sampling criteria. The second separation stage must be capable of removing all remaining aerosol with a size greater than $0.8 + 0.1$ micrometer aerodynamic diameter from the sample stream. Finally, the third stage must collect the aerosol smaller than 0.8-micrometer diameter. This final sample contains most of the diesel particulate material present in the mine air plus a small amount of mineral dust contamination, usually less than 10%. If a sample flow rate of 2 liters per minute is used and gravimetric analysis is to within 0.1 mg, an aerosol concentration smaller than 0.8 micrometer should have a limit of detection of 0.3 mg/m^3.

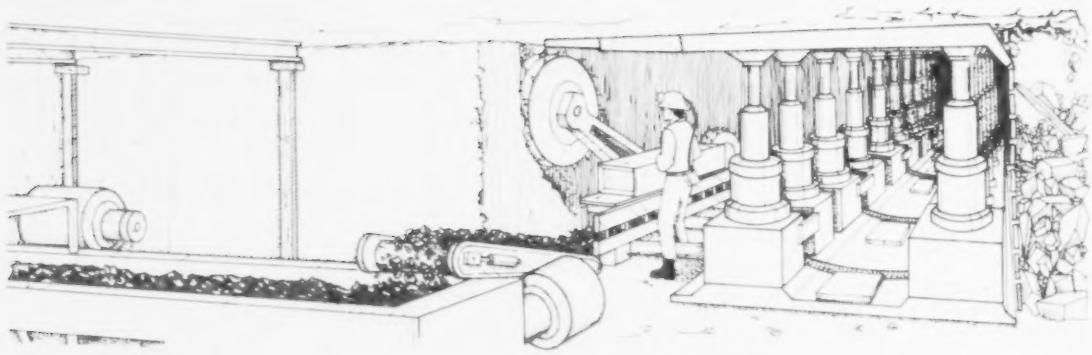
The prototype personal diesel aerosol sampler employs inertial impaction to meet performance requirements. The first stage, sample inlet-preclassifier, is a composite impactor with an aerosol penetration efficiency that conforms to the BMRC respirable dust sampling criteria. The second stage is a multiple-orifice impactor with a sharp separation or cut size that passes only aerosol smaller than 0.8 micrometer. The final or collection stage is a filter. This instrument is a research prototype and the design permits the second stage impaction substrate to be removed for gravimetric and chemical analysis.

In 1988 the Bureau organized and hosted a meeting of the Organization for Economic Cooperation and Development Nuclear Energy Agency (OECDNEA) at the Twilight Mine. The Bureau operates the Twilight Mine in western Colorado as a unique underground research facility for conducting radiation studies in an in-mine environment. OECDNEA represents 24 of the world's most developed nations and was founded in 1972. In 1983, OECDNEA established an International Intercalibration and Intercomparison Program to resolve disagreements and assure high-quality standards in the measurement of radon, thoron, and their daughters. The Bureau's radiation calibration laboratory and Twilight Mine facility were chosen from many laboratories to be the regional calibration laboratory for North America. The purpose of the OECDNEA meeting at the Twilight Mine was to ensure that proper international standards are established for the measurement of radon daughters in underground mines. The Bureau's experimental mine facility provides an ideal environment for such intercomparisons and the results from the international meeting indicate that it will be very useful in establishing standards for such measurements conducted under actual underground mine conditions.



A prototype personal diesel aerosol sampler has been developed for use in research to determine the occupational health effects of exposure to diesel particulate emissions.

Roof bolts are used to provide added support to the roof in underground mine gate road entries.



Optimum multientry designs and movable roof supports offer increased protection for miners in underground longwall coal mining operations.

Ground Control. Over half of the current longwall faces in U.S. coal mines operate under more than 1,000 feet of overburden. As shallow deposits are worked out, the number of deep-cover faces can be expected to increase. Large depths of cover primarily affect the gate entry systems, which are subjected to extremely high abutment loads that can result in roof failure, floor heave, and pillar bumps. These high loads also cause blockages in the critical escapeways.

Multientry (three or more entries) systems are used on all but eight of the current deep-cover longwalls. In the East, almost all of these mines employ large, stable pillars between the entries to control the abutment loads. In some cases, pillars as much as 200 feet wide have been necessary to achieve acceptable mining conditions; such large pillars are difficult to develop and result in low recovery percentages. One possible alternative to large pillars is to use small, yielding pillars that transfer load. While such designs have been used widely in the West, they are very rare in the East.

The Bureau recently studied an experimental, five-entry, yielding pillar design in a Kentucky longwall coal mine. The site was located under 1,800 feet of cover, and the yielding pillars were only 20 feet wide. Ground control instrumentation was installed throughout the site, and entry stability was monitored during the entire longwall mining process.

Adequate ground control could be maintained when enough supplemental support, such as cribs and posts, was installed. In fact, the yielding pillars provided better ground control than a nearby design that employed 60-foot pillars. It was concluded that yielding pillars could be used in deep-cover longwalls when unacceptable large pillars would otherwise be necessary. Research is developing guidelines for multientry yielding pillar systems, including pillar size, number of entries, and artificial support.

Bureau research in remote sensing has demonstrated the geologic lineaments (linear features of the Earth's surface) mapped from Landsat satellite images can be used to determine the extent to which geologic structures affect ground control conditions in underground coal mines. The lineaments are often caused or affected by subsurface fractures that can extend through to the mine level. Such fracturing can cause ground instability and lead to safety hazards and disruption of the mining process.

Bureau studies in central Utah led to the development of a potential hazards analysis methodology where geologic, geophysical, and mining data are combined to produce a potential-hazards or "degree-of-risk" map for a given mine property. Mines in this area of the western coalfield have consistently shown on 80% correlation between the known locations of ground control problems and the areas projected to have potential problems based on the lineament analysis. This high correlation holds true both for mines where a number of sources of data were incorporated into the analysis and for mines where only the lineaments were available for analysis.

Studies have also been conducted in northern Alabama to determine if the methodology proven successful in Utah could be applied to the eastern coalfield. Because the study site is close to the Appalachian fold belt, an area of intense compression and tectonic activity in the past geologic time, the coal-bearing rocks have been subject to more fracturing and deformation than those in the Utah study area. This greater degree of fracturing in the Alabama study area is reflected in the large number of lineaments that are apparent on remotely sensed images.

Thus far, research results for the Alabama area indicate lineaments have the same orientation as the regional fracture pattern, but differ from local fracture patterns adjacent to the lineaments themselves. This indicates that the lineaments are actually zones of fractured rock that, because of differential erosion and vegetation patterns, appear as linear features when viewed from a distance, as with remote sensing techniques. Presumably, these linears are governed by fractures in the basement rock.

The lineaments generally match the fracture trends measured in mines. There is also a statistical relationship among the number and location of roof falls and the location of lineaments. Because most ground control problems in mines can be related to ground conditions predictable from geologic lineaments, a potential-hazard map can be derived for individual mines from remote sensing data analysis. This hazard prediction methodology can be used as a ground control planning tool to improve the safety and productivity of underground coal mines.

Blasting overbreak contributes to ground control problems such as unstable highwalls in surface mines and dangerous rooms, drifts, and stopes in underground mines. Controlled blasting is a particularly attractive technique for reducing the hazards of overbreak because it is preventative, rather than corrective in nature. By maintaining, to the greatest extent possible, the natural strength of the rock structure, the need for subsequent corrective ground control measures is reduced and the long-term stability of the highwall or opening is enhanced. Recognizing this situation, the Bureau is examining blast designs that reduce damage to the rock beyond the planned excavation limits.

Results to date for both underground and surface mining have shown that selective energy reduction and more accurate initiation timing of critical blastholes does reduce overbreak. At the White Pine copper mine in Michigan, four blast designs were studied in a main heading. The best results were obtained using a combination of reduced energy in the rib holes and more accurate fast delay initiators. Underground tests are being done at the Homestake gold mine in South Dakota. Test results in a large-blasthole-diameter vertical crater retreat stope were favorable, using decoupled explosive charges in the hanging wall holes. Surface mine tests are also in progress at the Black Butte coal mine, Rock Springs, WY, where a presplit is used to form the highwall prior to blast casting. Blast designs for Black Butte were developed from earlier tests at the Rockwell coal mine in Wisconsin where selective reduction of explosive energy in the critical stemming zone resulted in backbreak.

In order to choose a mining method and mine design having lower rock burst potential, the conditions that produce rock bursts must be understood. Two conditions must be met for any rock burst to occur. First, there must be a large amount of stored strain energy available for sudden release. Second, there must be a triggering mechanism to release this energy. Methods of calculating available energy have developed along with advances in numerical modeling.

The first method to become popular was called energy-release rate, or ERR analysis, and is generally conducted with an elastic boundary element model. This approach examines change in energy with removal of each ore block. The energy released by excavation is shifted to other parts of a mine as strain energy. Although this method does not explicitly determine if the shift in energy triggers a rock burst, a greater shift in energy is expected to have a greater probability both of triggering a rock burst and causing a more dangerous rock burst if triggered. Thus, the mining method and sequence that produce the least maximum energy release per block of ore are preferred. This method of analysis is being extended to include inelastic dissipative mechanisms that release energy from the system in a safe, controlled manner. In this way, the effects of destressing measures, blasting overbreak, and time-dependent fracturing can be analyzed. For example, rock cores in the laboratory will often fail violently when loaded quickly, but when loaded slowly will dissipate much of their stored energy through microfracturing and will fail without violence.

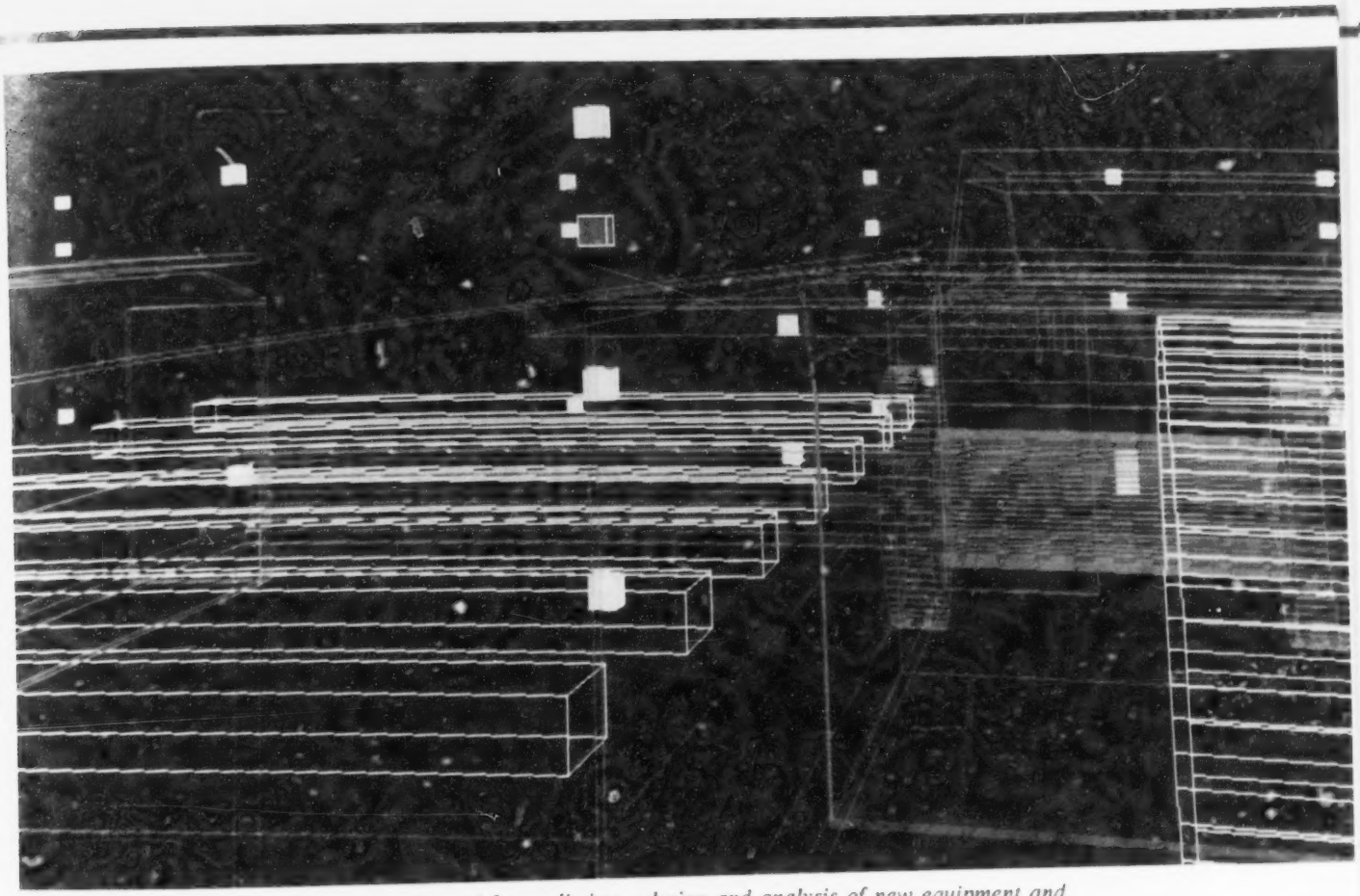
The various modes of triggering instability are harder to analyze but are essential to a complete solution. A number of triggering or instability mechanisms, including slip along faults, surface buckling, and pillar crushing, have been identified. These mechanisms hold the key to understanding why some deep mines experience rock bursting while others do not, and why different types of rock bursts dominate in different mines.

Predicting the type of rock burst can be a key factor in efficiently designing a mining method, mine layout, ground support system, and destressing procedure. The Bureau is conducting basic research on rock bursts that involve surface buckling around mine openings and those that involve propagation of shear fractures.

In all of these efforts, the emphasis is on developing a theoretical and mathematical framework for analyzing rock burst potential. Such a framework should reveal general rules of thumb that can be incorporated directly into mine and support design as well as numerical models. One of the most valuable results to date is a realization that measures to reduce the rock burst hazard from one type of triggering mechanism may not reduce rock bursts caused by other mechanisms and may, in fact, encourage them. Thus, a designer must take care that one problem source is not exchanged for another. A solution to the rock burst problem lies in understanding the necessary conditions for rock bursting. Such knowledge will enable mining personnel to assess the rock burst hazards and optimize mining operations to avoid these hazards.

Human Factors. Because of the unique environment in underground mining, mine equipment must be massive and rugged enough to withstand a tremendous workload. Often the design of the mining equipment stresses functionality and production rather human operator comfort and convenience. This has resulted in many classes of mining equipment where the operator's ability to safely control the machine has been severely restricted.

A model to assist in the design and analysis of underground mining machine operator stations, from a human engineering standpoint, is being developed by the Bureau. The crewstation analysis program is to be used by equipment manufacturers and mining companies for the preliminary design work on new machines, and to evaluate proposed modifications of existing machines in terms of good ergonomic design principles. These design criteria include field of vision, an assessment of control reachability, an anthropometric analysis, and an illumination analysis. The model gives the designer a flexibility for experimentation with the development of equipment that is not practical using conventional techniques requiring actual mockups.



The crewstation analysis program can be used for preliminary design and analysis of new equipment and evaluation of proposed changes to existing equipment.

Mine fires occur at a rate of approximately 25 per year. A major mine fire disaster occurred at the Utah Power and Light Wilberg Mine in December 1984. Preliminary evidence gathered by the Mine Safety and Health Administration (MSHA) indicates that ". . . some of the 27 victims did not have basic knowledge about how to start and use the SCSR devices available to them, and they were unaware of the critical need to protect their lungs from the smoke- and carbon monoxide-contaminated atmosphere created by the fire." More recently, a mine fire occurred in western Pennsylvania in March 1988. Three underground mining crews were inundated by heavy smoke sometime after 10 p.m. Disaster was averted, in this instance, by the fact that all the workers were able to don their self-contained self-rescuers (SCSR's) and rapidly find their way to fresh air.

These two incidents illustrate rather well the progress in SCSR training and the contributions of Bureau research. At the time of the Wilberg disaster, the Bureau had just initiated a broad program of research to develop techniques for teaching and assessing nonroutine mine emergency skills. By the time the mine fire in western Pennsylvania occurred, many of the training materials and procedures that grew out of that effort, including an instructional package for the 3 + 3 SCSR donning method, were being distributed by the National Mine Health and Safety Academy. In fact, MSHA had used findings from the first phase of the Bureau's SCSR research as an important basis for the promulgation of an Emergency Temporary Standard that required all persons entering underground coal mines after September 28, 1987, to have hands-on instruction on how to don the apparatus. The miners in the western Pennsylvania mine fire on the night of March 7, 1988, had received this hands-on experience and, as a result, successfully escaped the fire.

Bureau SCSR training research continues as field investigations have focused on the effect of the instructional method on donning performance, defining the degradation of donning proficiency over time, and the development of SCSR training simulators that are less expensive and

Training in tasks as fundamental as the correct position for putting on a self-contained self-rescuer can result in miners' surviving a mine fire disaster.

more hygienic than the actual respirators used in conventional hands-on SCSR training. It is anticipated that industry use of this research will integrate training with routine types of underground mine emergency preparedness procedures.

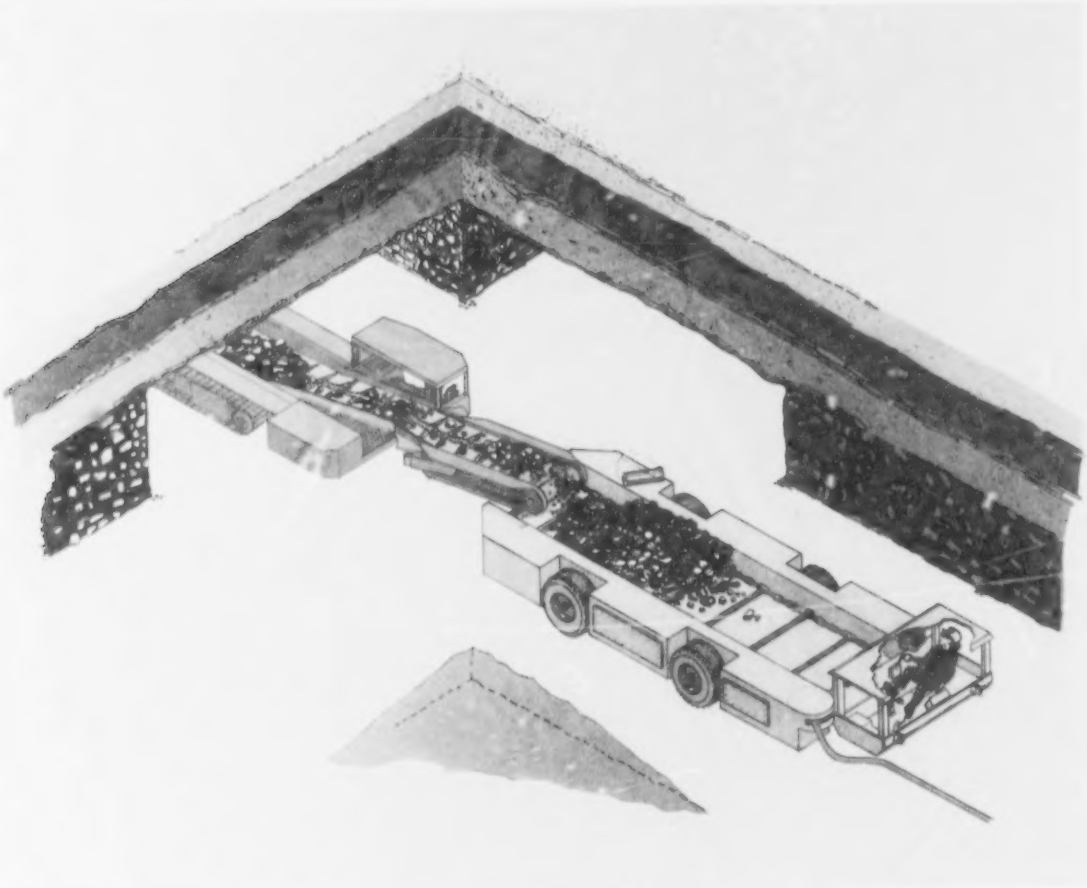
The Bureau has developed and made available, through the National Mine Health and Safety Academy, Beckley, WV, a human factors in mining search system and a user's guide. This computerized information retrieval system provides relevant human factor or ergonomic information from journal articles, research reports, seminars, conferences, etc., in terms of the following 19 categories.

Anthropometrics, biomechanics, and work physiology
Cost-benefit analyses
Mining equipment: auditory devices, canopies, controls, operator compartments, and visual displays
Female miners and female workers
Handtools
Human error and human reliability
Human factors: applications, methods, principles, and studies
Illumination
Job or work design and task analysis
Manual materials handling and back injuries
Noise: its control, effects, measurement, and standards
Organizational and management practices
Personal protective equipment and clothing
Psychological factors: absenteeism, behavior modification, incentive plans, job satisfaction, motivation, stress, and employee turnover
Safety assessment methods
Thermal stress
Training: cost-effectiveness, methods, principles, results, and studies
Vibration: machinery, tool, limbs, and whole body
Visibility

Although the emphasis has been on obtaining written material dealing directly with mining, publications that might be applicable to mining from other areas of research are entered into the system for those categories where little mining-related research has been done. Over 750 abstracts have been entered to date.

Mine Safety Systems. Cabs and canopies installed on underground coal mining face equipment in high seams have an impressive record of preventing fatal and nonfatal operator injuries. The Mine Safety and Health Administration (MSHA) estimates that from 1974 to 1985, these protective structures kept 233 lives from being lost as a result of roof falls. Unfortunately, the successful application of cabs and canopies has occurred almost exclusively in relatively high coal seams. A 1982 survey showed that for working heights below 48 inches, only 27% of all face equipment had protective operator structures. For working heights below 42 inches, the percentage of equipment with cabs and canopies dropped to 2%. While the availability of protection in working heights below 48 inches is low, the need for protection is high. For the 1980–81 period, there was a total of 2,212 fatal and nonfatal equipment accidents in working heights below 48 inches. It is estimated that 71% of these accidents could have been prevented had protective structures been employed.

In the investigation of operator compartment conceptual designs for thin-seam shuttle



A transversely mounted end-cab design concept would provide operator protection on thin-seam mining equipment.

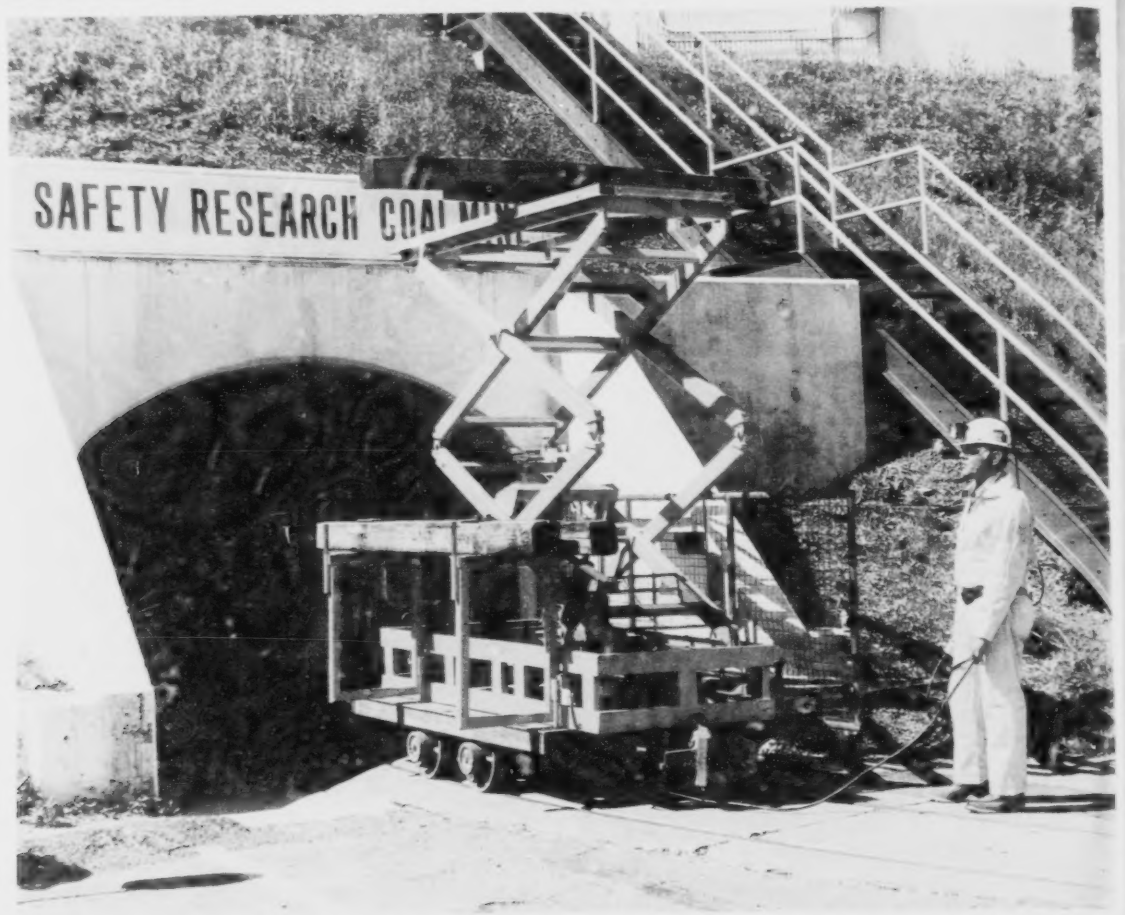
cars, a transversely mounted, end-cab concept was selected for further detailed design; wooden and steel full-scale mockups were constructed. The final concept design resulted in a 36-inch-wide, 72-inch-long, 36-inch-high prototype that can operate in 40-inch coal seams.

Safety standard tests conducted on the operator compartment resulted in no permanent deflection to the canopy when raised to its highest position, which indicated full compliance with MSHA standards.

Manual materials handling represents a critical and persistent source of personnel injuries in underground coal mining operations. In 1983 and 1984, this category of accident accounted for 35% of all lost-time injuries. Approximately 26% of all manual material handling related injuries are associated with the performance of mine maintenance or equipment maintenance tasks.

A detailed analysis of mine and machine maintenance-related tasks was made to identify sources of injuries. It appears that most of the hazards associated with material handling in underground coal mines results from the lack of properly designed and easily accessible material-handling tools, devices, and vehicles. Mine personnel traditionally rely on crowbars, a "couple of extra hands," and makeshift tools to manhandle even the largest components on mining machinery. Similarly, lacking appropriate tools, carts, and other handling devices, mine personnel manhandle timbers, posts, beams, and other heavy materials on a continuing basis. This analysis also revealed that what is needed is not another complex, powered vehicle designed to perform any and all maintenance jobs. Rather, what is required is a series of simple, task-specific tools, aids, and devices to be housed and used in the working sections and maintenance areas.

Based on this research, concepts for simple devices to help reduce manual materials handling were developed and evaluated. Particular attention was focused on making the designs practical, low cost, and easily fabricated, so as to be



A timber car is being evaluated as a device to help miners handle heavy and awkward materials undergrou in order to reduce injuries associated with these tasks.

broadly applicable in underground operations. Where possible, the designs were simplified and off-the-shelf components used to permit fabrication of the devices by mine site personnel. Six of these devices were fabricated and delivered to operational underground coal mines for testing and evaluation. The six devices included a scoop-mounted lift boom, a machine-mounted swivel crane, a heavy component lift-transport, a mine mud cart, a container-workstation vehicle, and a timber car.

Bureau research has estimated that delays due to electrical component failure cost 32% of total available time during a production shift. The Bureau is investigating procedures to identify deteriorating electrical components prior to actual failure. Using simple, cheap, electrical sensors on critical components, such as electrical motors, sophisticated signal analysis can be performed in real time to sense deterioration in electrical performance.

Electrical failure in squirrel cage induction motors usually begins as a breakdown of the stator insulation, allowing current to leak through an abnormal path. This process of insulation breakdown is used as the basis for quantifying progressive deterioration of motors. To create the necessary mathematical relationships, normal and deteriorated conditions are simulated on a laboratory induction motor system. The models created thus far can accurately evaluate insulation deterioration in a motor, using only quantities measured at the motor terminals. The predictions are independent of the location of the leakage path within the motor, the severity of the leakage, and motor loading. A single model can be used for a range of motor sizes. The generic nature of this research means that it can improve productivity throughout American industry and generate benefits far greater than those estimated for the coal industry alone.

The Bureau is investigating the relationship between current loading (ampacity) and the resulting temperature rise for the portable power cables used in underground coal mines. The study involves determining the effects of

"Expert" systems are used to provide advice on factors affecting methane control and dust control for continuous miners and longwall shearers.

increased ampacities and higher insulation temperatures on cable life.

Through accelerated life tests of cable insulation, the Bureau has developed models that relate insulation life to operating temperature. Extrapolation of the experimental data to rated temperature yielded insulation lifetimes far beyond those seen in actual operation, indicating that mine trailing cables fail from mechanical abuse long before the insulation degrades thermally. Because mine cables do not supply power continuously, their cyclic loading may allow further increases in ampacity.

Tests indicate that existing cable sizes may be reduced without sacrificing safety. Results from ampacity tests, insulation life tests, dielectric tests, and mechanical strength tests will be combined into a coherent set of recommendations for portable power cables. The use of smaller cables could have a profound positive effect on the U.S. mining industry, which consumes approximately 9,000,000 feet of trailing cable annually. The incidence of back injuries incurred in handling heavy cables would also be reduced.

The Bureau has introduced three expert systems that advise on factors affecting mining health and safety: dust control for continuous miners, dust control for longwall shearers, and methane control. All three systems inquire into the nature and extent of the problem. Advice given does not focus on a single issue, but may suggest a variety of approaches consistent with the ability of the operator to implement them.

The methane control system is designed to handle methane drainage, frictional ignitions, and outbursts of methane. Readily available data are used, such as methane flow rates, coalbed depth, presence of faults, ventilation rates, and mining method. If users lack data, the system can supply typical values for them. The continuous miner system seeks first to determine the source of the dust, based on user response about the ventilation system, mining sequence, and compliance with Mine Safety and Health Administration standards. For example, if the dust con-

trol system decides that the problem is the bolter, it focuses on bolter maintenance.

The longwall system has three parts: (1) advice for new users on the basic dust control measures every longwall should employ, (2) advice on several more refined approaches if the basic measures do not achieve compliance, and (3) a menu for users with specific interests.

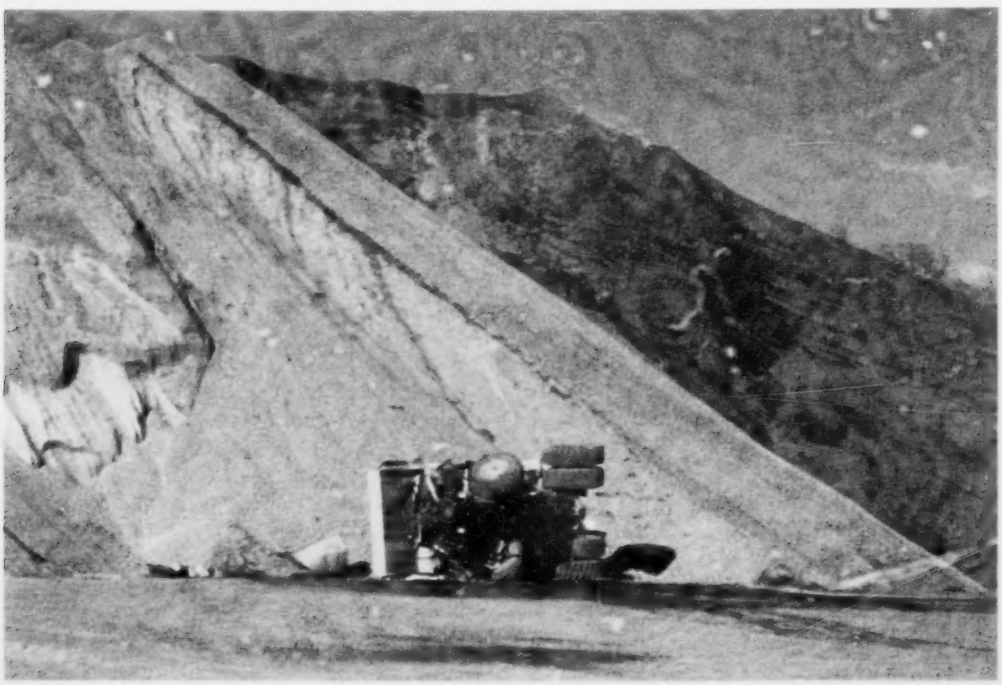
The three systems were all written using an expert system shell. The systems are the first of a series of Bureau expert systems, all of which will run under the same software package. Feedback from users has permitted improvements and has generated a valuable set of guidelines for future expert systems.

Mine equipment, particularly in the surface mining environment, has evolved over the years into large, complicated machines. As a result of this evolution, significant productivity gains have been realized that, in turn, have allowed the mining industry to develop and mine lower grade deposits. Commensurate with increased mechanization of the mining process has been the need for greater vigilance in the safe operation of such machinery.

The Bureau's conveyor belt research was previously directed at why spillage occurs with blade-type belt cleaners. The results of that work led to an understanding of the fundamental cleaning mechanisms for scraper blades. Blades always showed a similar uneven wear pattern that would allow moist, fine material to remain on the belt and ultimately generate a spillage problem. Bureau engineers developed a novel blade design that shows promise as a means to solve this problem.

Research is currently focused on the application of predictive maintenance. Predictive maintenance is the science of determining the current machinery health and predicting when maintenance will be required. Reliable maintenance prediction will allow for properly scheduled, cost-effective maintenance and reduce miner exposure to the dangers of becoming caught in rotating components. Predictive maintenance uses vibration signature analysis techniques to determine the health of a piece of machinery. When a bearing, gear, or other rotating component wears, the vibrations of the component change in a manner characteristic of the damage.

Such diagnostic techniques are commercially available but current technology requires each individual bearing to be monitored manually or remotely. For conveyor systems with hundreds of bearings, these techniques are expensive and impractical. Research is being conducted to trace vibration signal paths through the machine which will diagnose the condition of the conveyor system and pinpoint specific "bad" components. Computer analysis techniques will be used to interpret the recorded signal.



When slope instability results in a haul truck's tumbling over the edge of a stockpile or mine dump, the results can be disastrous.

Failures at mine dump points are particularly dangerous because of the height of the slopes and size of the mobile equipment involved. When slope instability or operational errors result in a haul truck tumbling over the edge of a stockpile or mine dump, the results can be disastrous. In most cases the accidents result in lost work time injuries and frequently in fatalities. In addition to the human cost, the vehicles involved frequently sustain substantial damage resulting in a financial loss for the mine operation.

The Bureau is addressing the problem of dump point failure through the identification and analysis of those factors responsible for failure. Computer modeling techniques are being developed that better define the relationship between dump point failures and equipment operation near the slope edge. Analysis of the parameters relating to slope failures will allow the development of guidelines that will assist the mining industry in the construction and safe use of stockpiles and dump points. Basic research is also continuing in the identification and characterization of acoustic signals that may act as a precursor to slope failure.

Highwall outcrops adjoining abandoned strip mining sites contain large quantities of unreclaimed coal reserves. It is estimated that 25,000 miles of highwall terrain exists, with 40% of this in the Appalachian coalfields alone. Very little extraction of these coal reserves occurs because present mining methods lack the specialized qualities required by the unique mining situation.

The Bureau has developed a unique highwall mining system that is expected to allow the extraction of a significant portion of these highwall coal reserves. The system requires only three workers, none of whom are located in the mine entry, and places the equipment operator in a safe and comfortable enclosure outside the mine. Thus, high productivity and very safe operation are expected. The principal system components are a modified Jeffrey model 102HP thin-seam continuous miner, a multiple unit continuous haulage system, a computer-based remote control system, and other support equipment located on the highwall bench.

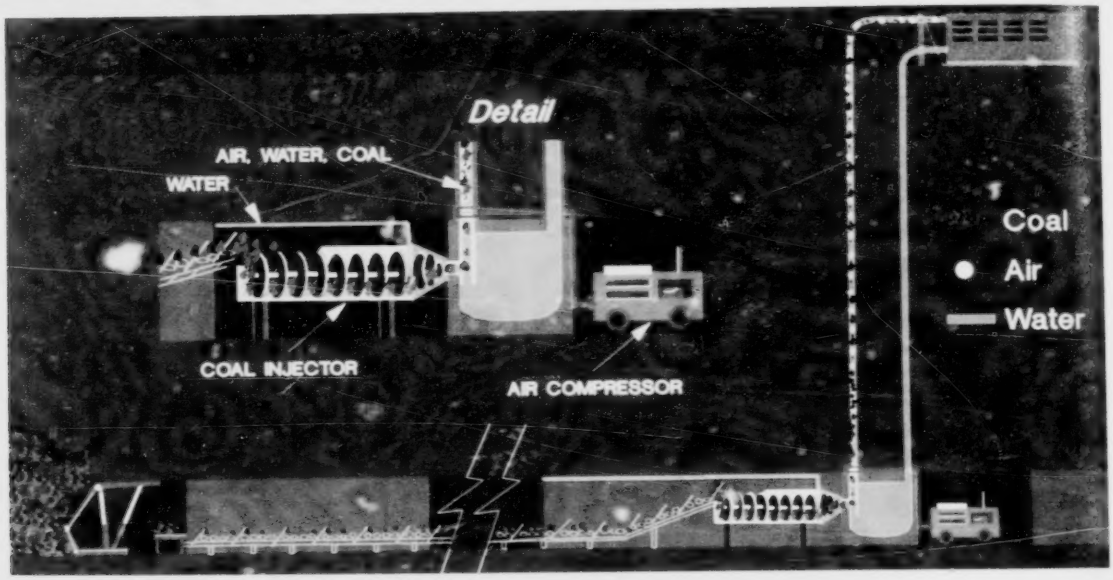
A computer-based electronics system supervises communications between the operator station, located on the highwall bench, and the mining equipment. Major additions to the continuous miner include three video systems, explosion-proof housings containing the electronics, and hydraulic, temperature, current, sound, linear displacement, methane, and heading sensors. The electronics system employs two microcomputer systems—one in the operator station and the other on the continuous miner. Operator commands, video signals, and sensory data are transmitted between the station and the mining equipment over cables run along the standard power and water lines. A laser alignment system provides the ability to maintain parallel entries. Evaluation of the highwall mining system in the Bureau's mining equipment test facility gave overall positive results. The complete system is being deployed at a highwall site in northern West Virginia. At a later date, a modified version of the mining system will be deployed at a deep mine worked by the room-and-pillar method.

Computer-based remote control of mining systems is a worthy present-day application of advanced electronic technologies. It is an area that holds great promise for increasing productivity, promoting safety, providing new mining systems, and expanding the recovery of coal reserves. Moreover, such systems will bridge the gap between current, worker-intensive methods of controlling mining equipment and the highly automated systems expected in the next 10 to 20 years.

Powered haulage is a major source of injuries and fatalities in underground coal mines. In the past 3 years (1985–87), there were 33 fatalities and 2,992 days lost because of injuries from powered haulage accidents. Current means of underground coal transport include shuttle cars, scoop trams, chain conveyors, underground rail, and conveyor belts. Each link in the total coal transportation system has inherent safety hazards.

The Bureau has undertaken an extensive long-term research program to eliminate haulage hazards through major redesign of underground coal transportation systems. The goal of this research is to move more coal out of the mine with less risk to underground mine workers.

Bureau scientists have identified air-lift coal hoisting as a new haulage system with potential to significantly improve safety. Air-lift hoisting is based on the principle that a vertical lift can be created by injecting compressed air into one column of a two-column hydraulic loop. This creates a pressure differential between the two columns by reducing the density of one column. This results in an upward flow in the air-water column and a downward flow in the opposing water column. Vertical flow is enhanced by the expansion of air bubbles as they rise in the air-water column. The air-lift hoist could potentially be used to vertically transport coal out of an underground mine through shafts located close to the mining face, thus eliminating long, horizontal hauls using belts or rail.



An air-lift coal haulage system would eliminate hazards associated with conventional haulage systems.

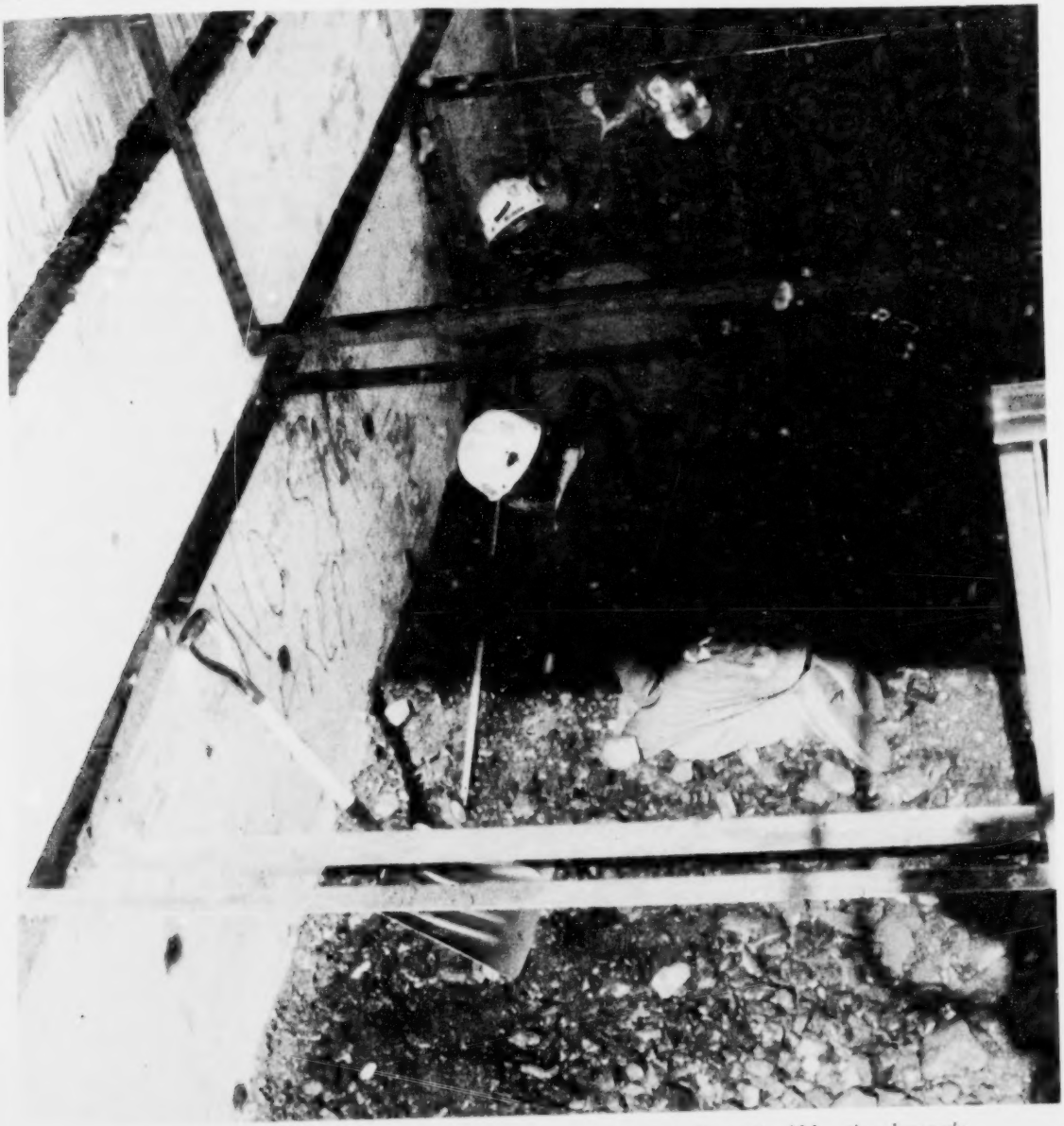
A research program has been initiated to verify the feasibility of an air-lift coal hoist through a set of tests using bench-, intermediate-, and full-scale models. If proven feasible, the air-lift hoist will be integrated into a complete coal transportation system from the production face to the processing plant.

Mine Disaster Prevention. Approximately 20% of U.S. underground coal mine fires are caused by the spontaneous combustion of coal, and their number is increasing with the greater consumption of lower rank coals, extraction of deeper mines, and the expansion of longwall mining. Self-heating of coal usually occurs in a worked-out or gob area, where it is not easily detected. The resulting fire presents a serious safety hazard and often requires sealing large sections of the mine or the entire mine for long periods.

For several years the Bureau has been conducting experiments on the self-heating of coals in laboratory-scale test systems. However, in actual self-heating events in coal mines, much larger coal masses are involved. To adequately reproduce such conditions, a large-scale test facility was constructed to simulate a gob area. A 6- by 6- by 15-foot insulated enclosure has been equipped with instrumentation to monitor and record temperatures and gas concentrations. The enclosure can hold up to 15 tons of coal. As the coal is loaded into the enclosures, 60 temperature probes and 7 gas sampling lines are inserted at preselected locations throughout the coalbed. Suction pumps transport gas samples through the lines to instruments that measure oxygen, carbon monoxide, carbon dioxide, and methane. Electrical heaters are also buried in the coalbed to stimulate a heating event if necessary. The outputs of the temperature sensors and gas analyzers are connected to a sophisticated automatic data acquisition system. After the coal is loaded, the enclosure is sealed and a regulated flow of air is passed through the bed to provide sufficient oxygen for self-heating of the coal; the airflow exits the coalbed through an exhaust stack. Because the self-heating process is slow, a test with a particular coal can last up to 6 months.

The initial experiment in the facility was conducted with freshly mined coal from Colorado. The experiment consisted of two phases: a self-heating phase and a stimulated heating phase. The self-heating phase lasted 3 months, during which time the maximum temperature in the coalbed reached 35° C and then began to fall. The heaters in the coalbed were then turned on just long enough to stimulate a sustained heating event. Coal temperatures in the bed reached 350° C and were increasing at the rate of 5° C an hour when the airflow was stopped and the experiment ended. Additional tests are planned with different coals to gain a better understanding of the variables that control the self-heating in a large mass of coal and to evaluate preventive measures.

Under certain conditions, sulfide minerals undergo self-heating as a result of exothermic oxidation reactions. This self-heating can lead to the spontaneous combustion or ignition of carbonaceous materials such as wood mine timbers



Temperature probes are inserted in a 15-ton coalbed to study coal self-heating hazards.

and timbering or even the sulfide minerals themselves. Sulfide self-heating also causes problems when explosives are loaded into blastholes that contain reactive sulfides or when reactive sulfides are found in or near coal seams. The Bureau has completed research to delineate the conditions that cause self-heating and to measure the range of ignition point temperatures for a variety of common sulfide minerals. This information provides a baseline for comparing the effectiveness of methods used to inhibit the self-heating reactions and to rank sulfide minerals as to their potential ignition hazard.

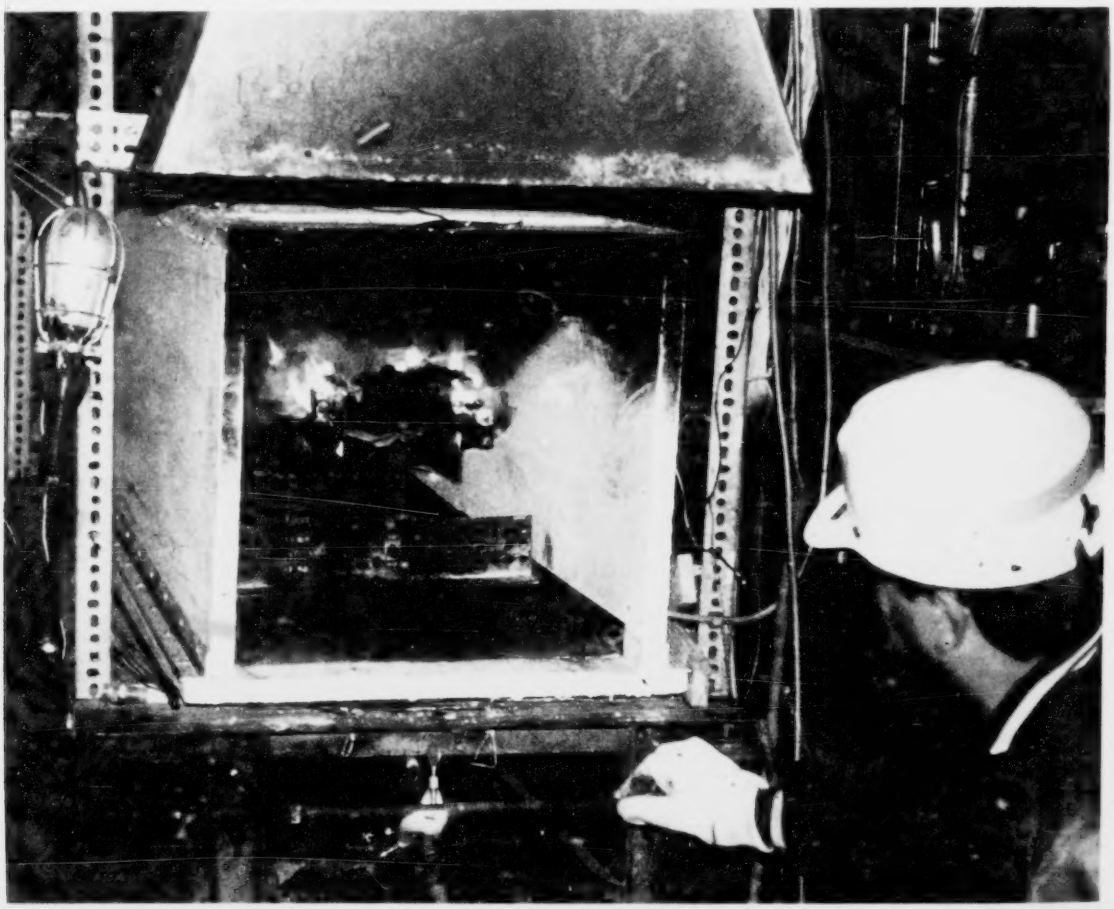
Recent experiments have measured the relative degree of conversion of several pyrite samples to soluble iron sulfate, a product of the self-heating reaction, after a 24-hour exposure to oxidizing conditions. Results of this testing were highly significant. First, considerable variability in the reactivity of sulfides from different sources was observed, with the most reactive pyrite producing nearly three times the iron sulfate as the least reactive pyrite. Second, the presence of water vapor in the oxidizing atmosphere was shown to have a strong effect in promoting oxidation of pyrite.

In dry air, only about 2% of the most reactive pyrite was converted to iron sulfate. In air with 60% water vapor, the conversion to iron sulfate for that material increased by a factor of 15. The promoting effect of water vapor is observed at ambient mine temperatures and continues up to the ignition point of pyrite. Likewise, removing water vapor from the system slows oxidation, even at higher temperature.

In general, the iron sulfides, marcasite and pyrite, were the most reactive with ignition points below 300° C. For most of the sulfides, decreasing the particle size of the mineral sample caused the ignition point to be lowered. However, the presence of water vapor in the oxidizing atmosphere had a mixed effect on the resulting ignition point. The mineral sulfides, galena, sphalerite, and wirtzite, were also studied and appeared to be less reactive, with these samples failing to ignite when heated to 500° C.

The materials required for normal operations in underground coal mines, such as conveyor belting, can create fire hazards. About 20% of the underground coal mine fires during the past 5 years have involved conveyor belts, many of which had been approved, having passed the current small-scale Federal flame test for fire-resistant belting.

To evaluate the flammability hazards of conveyor belts under realistic conditions, the Bureau is conducting full-scale fire tests of rubber and polyvinylchloride belting in a surface gallery at the Lake Lynn Laboratory. A 90-foot-long tunnel coupled to a large ventilation fan is equipped with temperature sensors and instruments that measure combustion products. In a typical test, a 30-foot length of belting is placed on the top rollers of a conveyor belt frame and one end is ignited by a liquid fuel tray fire. Flame spread rates, fire damage, downstream air temperatures, and gas concentrations (O_2, CO, CO_2) are measured. The tests are being conducted at ventilation airflows ranging from 0 to 800 ft/min. Many of the belts examined burned rapidly at certain airflows, with flame spread rates as high as 20 ft/min. Large quantities of smoke and toxic combustion gases were generated as the belts burned. Several highly fire resistant belts that did not propagate flame under these test conditions were also identified.



The flammability of conveyor belting is assessed in a laboratory-scale fire test.

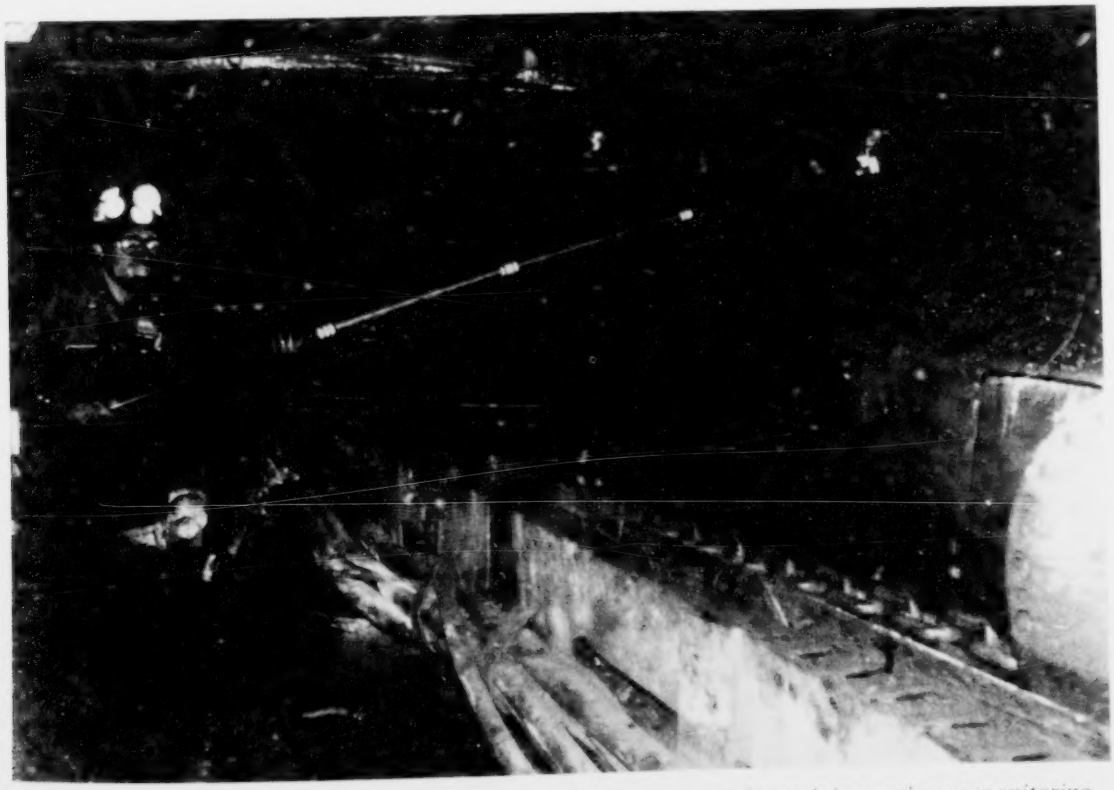
The results acquired from the full-scale gallery tests are being used to develop a reliable laboratory-scale flammability test for belting that is less expensive and time consuming. The test is conducted in a 1.5-foot-square by 6-foot-long ventilated tunnel with a 9-inch-wide, 5-foot-long belt sample. The sample is mounted on a rack and one end is subjected to the flames of a gas burner for 5 minutes. The airflow in the tunnel is set at 200 ft/min, which correlates with the worst case of 300 ft/min in the full-scale gallery test. The belt passes the test if a portion of the sample is undamaged by the fire.

The pass-fail results obtained for 17 conveyor belts in the laboratory-scale test were in excellent agreement with those obtained for the same belts in the fire gallery, based on belt fire damage. The laboratory-scale test procedure is expected to replace or augment the current inadequate Federal fire test standard for belting and thus significantly improve the fire resistance of conveyor belts for underground mines. This simple test could also be used by belt manufacturers for quality control purposes and for evaluating the fire performance of new belt formulations.

Face ignitions of methane occurring during longwall mining are a major concern for U.S. coal companies, and will continue to be as deeper and gassier seams are mined and as production rates are increased. There are three ways to reduce longwall face ignitions: (1) by controlling the ignition source, (2) by diluting the methane gas around the shearer to a safe range, and (3) by monitoring for methane at critical locations using an effective shutdown mechanism when methane concentrations exceed certain limits. The Bureau is actively pursuing research in all three areas.

Controlling the ignition source involves primarily the cutting bits on the longwall drums. The anti-ignition drum, which uses a water spray located behind each cutter bit to quench the hot streaks created by the bit when cutting rock, was developed by the Bureau a number of years ago. Research to optimize this development is continuing. An anti-ignition bit has also been developed.

The second approach is to dilute the methane gas around the shearer to the nonexplosive range. Many operators have increased the ventilating airflow on longwall sections to over 100,000 cfm for this purpose. It is very expensive to use such high air volumes and some additional problems are introduced by the extremely high air velocities. The Bureau is testing two techniques that will allow the operator to more



Measuring methane levels at a longwall face is a preliminary step in determining optimum monitoring locations for methane detectors.

effectively use the present ventilating air volumes. The first technique is the modified shearer-clearer system, which uses a series of strategically located water sprays mounted on the shearer body to direct more air toward the face, thus diluting methane liberated by the drums during cutting. The second technique is the ventilated drum, which uses water-powered extraction tubes built into the drum shell. Approximately 4,000 cfm of airflow is pulled from the coal face, back through the drum, potentially lowering methane concentrations. Both techniques effectively reduce the shearer operator respirable dust exposure. Evaluation of the effectiveness of the ventilated drum in reducing methane levels is being scheduled in collaboration with the Canada Centre for Mineral & Energy Technology.

The third approach is to monitor for methane at critical locations. This is an additional safeguard if other methane control techniques fail. Drastic differences in face methane liberation and emission patterns have been observed at a number of longwalls. To effectively monitor for methane, additional detectors, over and above the tailgate monitor, are necessary. The Bureau is beginning an evaluation to determine the optimum monitoring locations on the longwall shearer to quickly and effectively determine when methane concentrations are approaching the explosive limit. The goal of this work is a monitoring system that will disengage power to both cutting drums when methane levels are approaching the explosive limit.

Mine fire suppression systems are designed to automatically extinguish fires on attended and unattended equipment and are mandated by various Mine Safety and Health Administration regulations. However, the functional reliability of these systems has been called into question as a result of several recent mine fires. Bureau research was undertaken to improve system reliability through the development of systematic inspection, testing, and maintenance procedures.

The most successful inspection technique was found to be the measurement of functional parameters such as contact point resistance, battery internal resistance, water valve actuation energy, etc. Parameter measurement assures that impending failures and intermittent failures are identified as well as nonfunctional systems, thereby enabling mine personnel to take appropriate corrective action before the standard go, no-go testing would have revealed a problem. Training materials summarizing the parameter measurement technique were supplied to MSHA for inclusion in a National Mine Health and Safety Academy course on fire suppression devices for attended and unattended equipment in underground coal mines. A slide-tape module and accompanying manual are being prepared in cooperation with the academy for use in future courses.

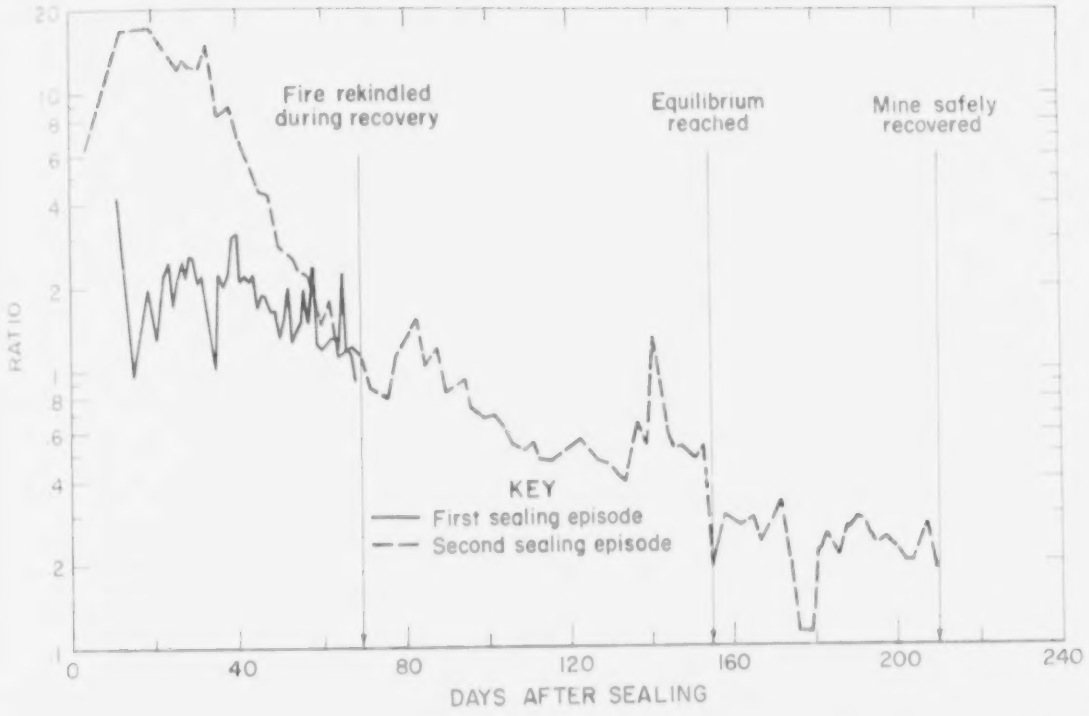
Combustibles that smolder as a result of friction or contact with hot surfaces do not, in many instances, produce levels of CO great enough to trigger alarms (approximately 15 ppm above ambient is required), yet produce copious quantities of smoke. This phenomenon is particularly apparent in conveyor belt haulage entries, where a number of frictional heatings at the belt drive have gone undetected by installed CO fire sensors, while the entries rapidly filled with smoke.

This problem was studied in a series of intermediate-scale smoldering belt fire tests using samples of approved belting. It was found that (1) smoke particles always preceded the production of any measurable level of CO during heating; and (2) the ratio of optical density of the smoke (expressed as m^{-1}) to the level of CO produced during steady-state smoldering averaged 0.12 m^{-1}/ppm CO.

Based upon these results, a smoke detector with an alarm threshold of 0.10 m^{-1} optical density would alarm, on the average, before the CO level ever reached 1 ppm. Moreover, visibility would be seriously diminished at CO levels of less than 5 ppm, significantly below that alarm threshold. Thus, smoke sensors are suitable for early detection of smoldering belts and should be the type of fire sensor used in belt haulage entries.

Mine fires pose a serious threat to the safety of underground personnel. Early knowledge of the location of a fire in a complex underground mine would greatly reduce the associated risks by enabling miners to choose the safest escape routes, would allow rescue teams to concentrate searches where survivors would most likely be found, and would enable firefighters to select the most efficient route to the fire and the most effective fire-fighting strategy. Once the fire location is known, other related aspects of the fire can also be inferred, such as intensity, fuel, and growth rate.

The Bureau has devised an approach for integrating in-mine fire detectors with a specialized ventilation network analysis computer model to enhance the decisionmaking information derived from conventional fire detection devices. The system utilizes real-time data from the fire detectors together with preprogrammed descriptions of the mine ventilation network to calculate the fire location. The system comprises three major elements: a network of underground fire detectors, a data communications system linking the detectors to the surface, and the net-



An index has been developed that can be used to determine when it is safe to open a sealed mine without danger of rekindling the fire.

work analysis software. The computer operates in a process control mode to monitor such system performance functions as detector operation and telemetry loop continuity, and in a computational mode to perform the real-time analysis of detector output data.

The results of a case study experiment involving fire simulations in a large multilevel mine ventilation network have established the capability of this system to identify the single network branch or pair of adjacent branches where the fire is located.

Mines are often sealed in order to eventually extinguish fires that cannot be safely controlled and extinguished using local, conventional techniques. The purpose is to allow the fire to consume available oxygen, progressively bringing to a halt any underground combustion. Once combustion has ceased at low oxygen levels, the affected coal cools to normal temperatures, attaining a state that is safe for the initiation of recovery procedures. The problem is to reliably determine when this state has been reached.

To address this problem, gas data were analyzed for a variety of coals to determine if there existed stable, equilibrium CO levels at normal temperatures within sealed atmospheres. Data from laboratory experiments and sealed mines indicated that a new index, called the R-index, could be correlated with the ratio of residual gas to oxygen. An empirical expression was derived for the upper limit of the R-index as a function of this ratio. Above this limit, the R-index values are not indicative of normal equilibrium conditions. The new index involves only a minimal number of gases, namely CO, O_2, CH_4, and C_2H_6. The O_2, CH_4, and C_2H_6 concentrations are used to calculate the combined air-, methane- and ethane-free gas concentration which is called the residual gas. The R-index is then defined as 100 times the CO in the sample.

When the ratio of actual R-index to equilibrium R-index is calculated to reach a value of 1.0 or less, the range of possible normal equilibrium has been reached. Equilibrium does not occur, however, until the ratio has stabilized at a value less than 1.0; the recommended period for which stabilization should exist is 30 days. For six mines sealed because of fire, this new method of gas analysis consistently indicated the true status of combustion in the sealed areas.

As evidenced by the number of fatal and near-fatal mine fires, miner safety is a major concern. Research is centered on novel ventilation techniques to reduce a miner's exposure to lethal concentrations of gas during escape.

One facet of this research uses fault-tree analysis to identify the ways in which fatalities

may occur during a mine fire. A working model of the fault tree was created that reveals fatalities are caused by numerous factors. Preliminary results, however, indicate that the occurrence of fatalities is greatly enhanced if certain events occur simultaneously. This work is supported by an expert panel selected from the mining community to find probability values for each event in the fault tree.

Another facet of this research provides mine ventilation plans for certain entries, defined as primary and secondary escapeways, to be used as escape routes during an emergency because rapid egress is crucial. In many mines, these passages abut each other. Although there are permanent structures (stoppings) designed to minimize leakage, a considerable quantity of air flows between parallel escapeways. The Bureau has performed research in an operating coal mine to determine how a fire could affect escape via the predetermined passageways. Initially, a simulated fire, using a tracer gas to represent contaminants, was set in a belt entry. Included in the test was a restriction in the belt entry similar to that expected from the throttling effect of a fire. These tests showed fireborne contaminants flowing to parallel intake entries, flanking the belt, that also served as escapeways. Additional tests were conducted in a three-entry mine having a belt entry flanked by an intake and a return; simulated fires here were located in the intake entry. Again, tracer gas was detected not only in the intake, but also in the belt and return.

The Bureau has shown that drilling of horizontal boreholes into a coalbed effectively removes methane in advance of mining and controls methane emissions during mining. However, to be effective, horizontal boreholes must be accurately drilled, simultaneously maintaining a vertical trajectory within the coalbed and a horizontal trajectory on the desired course. Maintaining this degree of drilling accuracy can be difficult, requiring bit inclination and azimuth to be surveyed frequently, usually at 10- to 20-foot drilling intervals. As boreholes are drilled to increasing depths of 1,000 feet or more, surveying with conventional wire-run surveying instruments can take as much, or even more, time than the actual drilling. Consequently, as boreholes penetrate deeper, drilling productivity decreases because of the increase in the time required to survey. The Bureau has played an active role in increasing the productivity of drilling horizontal methane drainage boreholes with the developmental and successful in-mine test of a prototype wireless survey system.

The wireless survey system consists of a downhole guidance probe and uphole receiver and uphole receiver processor. To conduct a survey, the downhole probe is activated by shutting off the high-pressure water flow to the bit. The downhole probe sensors then determine borehole position, including bit inclination, azimuth, and orientation of the downhole motor bent housing. The borehole data are then converted from analog to digital form and transmitted uphole by electromagnetically inducing a current (208-bit data string using 5-kHz carrier) onto the drill rod. The uphole receiving transformer picks up the transmitted data and relays them to the uphole receiver processor. The uphole receiver separates noise from the signal, amplifies the signal, and demodulates the data before transmission to the uphole processor. The processor then evaluates and converts the raw data into usable information, including bit inclination, azimuth, orientation of the bent housing, status of the downhole batteries, etc.

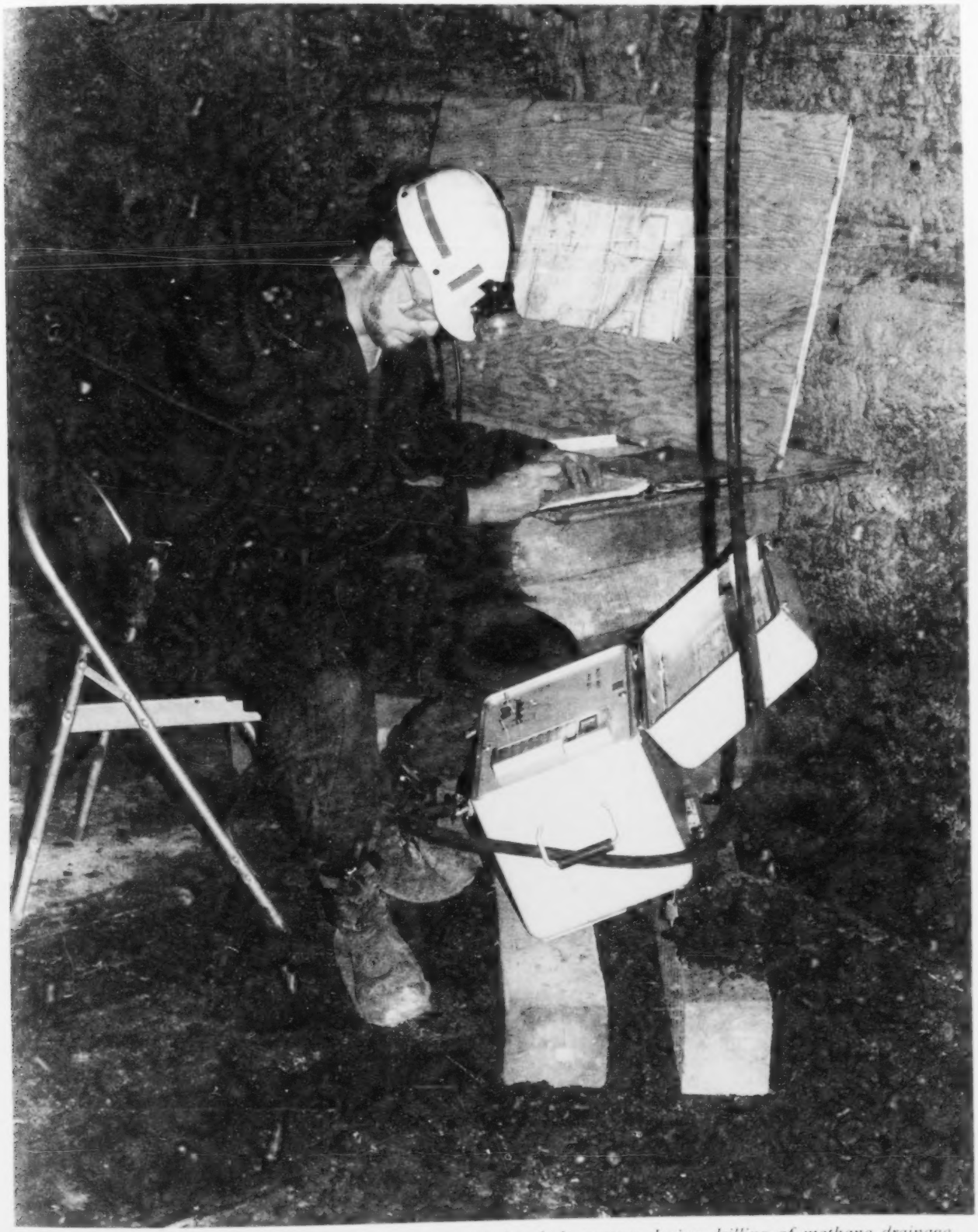
The wireless survey system was successfully tested at a southwestern Pennsylvania coal mine, where it reliably provided borehole surveys during directional drilling of a 2,608-foot horizontal methane drainage borehole used to shield a longwall gateroad development from methane emissions. Surveys, taken at 10-foot drilling intervals, took less than 1 minute each, even from a depth of 2,608 feet.

The Bureau demonstrated the accurate directional drilling of a near-horizontal borehole, drilled to intercept a designated target. The project was conducted for the Bureau of Reclamation at the Navajo Dam in northern New Mexico. The objective was to determine the feasibility of accurately drilling long near-horizontal boreholes, from the surface, in lieu of constructing a tunnel under an embankment dam from which shorter boreholes would be accurately drilled to control water seepage.

The right abutment of the Navajo Dam was chosen for the location of the demonstration borehole. The designated "punchout" was to occur by drilling approximately 890 feet of near-horizontal borehole to intercept a 5-foot-radius target located on the excavated sandstone wall near the top of the spillway.

A hydraulic core drill, a downhole motor equipped with a bent housing, and polycrystalline diamond cutter bits were used to drill the borehole. A single-shot directional survey instrument monitored borehole inclination and azimuth, and the orientation of the bent housing. The demonstration borehole was accurately drilled to a final near-horizontal depth of 885 feet, where daylight occurred. Final borehole elevation was 1.6 feet from the elevation of the target center, while borehole punchout coordinates were only 8.81 feet southwest of the target's perimeter.

As a result of the demonstrated accuracy, the Bureau of Reclamation contracted for the



The Bureau-developed wireless survey system can provide borehole surveys during drilling of methane drainage boreholes more rapidly than conventional wire-run surveying instruments.

accurate drilling of design boreholes as long as 600 feet from the inside of a short tunnel, to control water seepage in the right abutment. This resulted in a cost savings of $1 million from the original plan of constructing a longer tunnel and drilling 150-foot drain boreholes.

Permissible blasting procedures as applied in underground coal mining are not directly applicable to gassy noncoal mining, specifically to oil shale mines. The Bureau has been investigating the possibility of developing a safe blasting method for gassy noncoal mines, using commercially available blasting agents. This research has identified a generic family of explosives—ANFO-emulsion blends—that appear to be at least as effective as permissible explosives in preventing the ignition of methane and explosive dusts. Superior stemming materials have also been identified. Specific blend-stemming combinations are now being evaluated in an operating oil shale mine, where blasting performance and safety are being compared with those of ANFO rounds. It is anticipated that this work will lead to an approved blasting procedure for gassy noncoal mines.

The safety of using blasting agents in a methane atmosphere is evaluated at the Bureau's Lake Lynn Laboratory.

Minerals and Materials Science

Vulnerable Strategic and Critical Minerals

Magnetic properties of minerals. The publicity given to high-temperature superconductors has sparked considerable public interest. A fact often overlooked is that superconductors are already in use. Copper, stabilized with columbium and titanium, becomes a superconductor at the temperature of liquid hydrogen (4 K or approximately −260° F). A magnetic separator using this material uses only one-tenth the power, including the power to liquify the helium, required by a conventional magnetic separator. In addition, superconducting electromagnets permit far greater magnetic field strengths than are possible with conventional magnets. One current application is to remove discoloring iron impurities from kaolin.

Expanded use of superconducting magnets in the minerals industry is hampered by the lack of data available to predict how minerals will behave in the magnetic fields. The Bureau is isolating pure samples of minerals that show little or no response to conventional magnetic fields and is studying their response to very high magnetic fields. It is anticipated that this information will lead to new minerals separation processes that could be especially beneficial in concentrating minerals present in ores at very low concentrations. The current focus of this work is directed toward strategic and critical minerals, especially those for which the United States is highly dependent on imports.

Recovery of chromium, cobalt, and nickel from mixed and contaminated superalloy scrap. High-performance alloys, such as superalloys, are major consumers of strategic and critical minerals, especially cobalt. For such critical uses as in jet aircraft, these alloys require precise control over their composition. Impurities in alloy feedstock can not be tolerated as they could greatly change the properties of the resulting alloy. Recycling mixed or contaminated scrap is therefore impractical when producing high-performance alloys. However, recycling mixed or contaminated scrap to alloys with less critical composition control frequently results in the loss of one or more of the alloying elements in the scrap. For example, if a superalloy is used for stainless steelmaking, the nickel and chromium components are recovered but the cobalt component is effectively lost.

Bureau research is devising technology to recover a nickel-cobalt alloy from superalloy scrap, which can be recycled as superalloy feedstock. In the process, superalloy scrap in any form is melted to form anodes. Controlled oxidation of the melt removes most of the chromium, tungsten, tantalum, columbium, and other refractory metals as carbides, much of which reports to the slag where it can be recovered. The anodes are then electrorefined to form a master alloy, suitable for use when making a nickel- or cobalt-based superalloy. Iron and other troublesome impurities are kept at negligible levels in the final product by treating a portion of the anolyte.

Strategic and critical minerals from Alaskan and other domestic resources. The United States is dependent on imports for 60% to 100% of many minerals critical to its economy and strategic capabilities. Alaska and several other Western States are being assessed for potential resources because their mineral deposits are relatively unexplored. Alaska, in particular, has large areas that are restricted in use, and little incentive has existed for private industry to appraise mineral deposits in these areas.

Bureau field operations and research centers are pursuing a cooperative effort with private industry to explore ore bodies, conduct field tests, and acquire samples for laboratory and pilot-scale investigations. More than 60,000 pounds of ore samples have been obtained that represent potential resources for chromium, cobalt, platinum-group metals, columbium, rare-earth elements, tantalum, tin, tungsten, copper, zinc, and precious metals. Chromite ore samples from Alaska, California, Montana, and Oregon are being systematically studied with the goal of developing procedures and process data for the physical concentration of these ores, some of which contain accessory platinum-group metals. Processes using combined physical and chemical methods are being developed for Alaskan ores that contain tin, tungsten, columbium, tantalum, and gold. Chemical recovery procedures are being designed for processing rare-earth complex oxide ores from Alaska and sulfide ores from Oregon and Alaska that contain cobalt, copper, zinc, and precious metals.

Process design, engineering, and cost information resulting from these investigations will be essential in making land use decisions, including informed environmental regulations and wilderness land withdrawals, as well as political and economic decisions that affect the Nation's vulnerability to foreign dependence for these critical and strategic minerals.

Cobalt and manganese from seamount crusts. Ocean-floor mineral deposits offer the United States a potentially enormous source of mineral commodities, including those that are strategic and critical to the Nation. The Bureau is working to meet the information and technology needs of a new ocean mining industry.

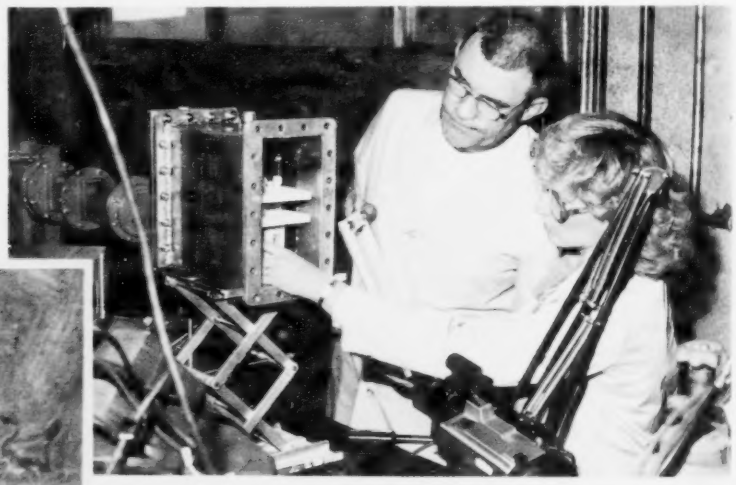
Methods for sampling and mining deposits thousands of meters underwater are being developed, and advances are being made in technology for upgrading and extracting the metals from the mined material. At all research stages, special consideration is given to preserving the ocean environment.

Bureau research is most advanced in the mining and treatment of cobalt-rich manganese crust, located on deep seamounts in the central Pacific. Bureau engineers have designed and tested a dredge capable of removing intact pieces of the crust from seamounts. Other engineers have devised froth flotation methods and a new hydrometallurgical extraction process for recovery of values from the crust. These methods conserve fresh water by using seawater as the processing medium; the hydrometallurgical process generates oxygen as a byproduct. It is estimated that if only 4% of the potential area was mined, the entire U.S. cobalt requirement could be met for about 75 years, and manganese for about 20 years.

Minerals Essential to the Nation

Microwave heating of ore minerals. Materials exposed to microwaves heat in proportion to their ability to absorb microwave energy. The amount of energy absorbed depends on the dielectric properties of each mineral and differs for different minerals. This ability to selectively heat minerals is unique to microwave energy and shows potential for applications not possible with conventional heating. Another useful property of microwaves is the ability to heat a material much faster than by conductive and convective methods.

Because metal content in most domestic deposits are low, concentration of the valuable minerals must be performed before final processing to metal. During comminution, it is desirable to fracture a mineral along its grain boundaries rather than fracture it through a grain. With the ability to fracture an ore along grain boundaries, the ore may not need to be ground as finely.



Microwaves heat different minerals in an ore to different temperatures, which produces stress cracks. This can improve liberation and reduce grinding costs. Electron micrographs show a mineral grain before treatment (top) and with resulting stress cracks (bottom).

Bureau studies have shown microwave heating to high temperatures induces stresses that promote grain boundary cracking. This pregrinding treatment has resulted in a substantial improvement in the grindability of iron ore samples.

Microwave heating can selectively change the chemical properties of the mineral components in an ore, whereby the minerals of value can be oxidized, reduced, or decomposed to facilitate extraction. Bureau research has demonstrated that the surface layer of pyrite grains are altered to a magnetic phase when irradiated with microwaves. Magnetic separation of altered pyrite from the more valuable minerals in an ore may be possible. The inherent selectivity of microwave heating has the potential to lower the cost of modifying minerals and provide new separation processes.

If microwave heating models for mineral processing techniques are to be developed, it is necessary to have data on dielectric properties of minerals. The Bureau has developed internationally recognized expertise in measuring dielectric properties of various minerals at microwave heating frequencies and is the only source making this information available to the scientific and industrial community. These techniques are expanding the knowledge base of microwave technology and incorporating the most advanced equipment available for these measurements. Because dielectric properties of a mineral vary as a function of temperature, the Bureau has also incorporated a method of heating the sample during measurement.

In situ leaching chemistry. In situ leaching is a promising technology that offers low-cost operation with no scarring of the landscape due to open pits, waste-rock dumps, or tailing ponds. Lower cost processing methods are needed in order for domestically produced copper to remain economically competitive throughout the world. Oxidized copper ores are likely candidates for in situ leaching because the contained copper minerals are leached very rapidly. Many factors control productivity of in situ leaching operations. One of the most significant factors is the occurrence of clays in the ore body. The presence of clays can lead to decreased metal recoveries because the cation exchange ability of clays extracts valuable metals from leaching solutions.

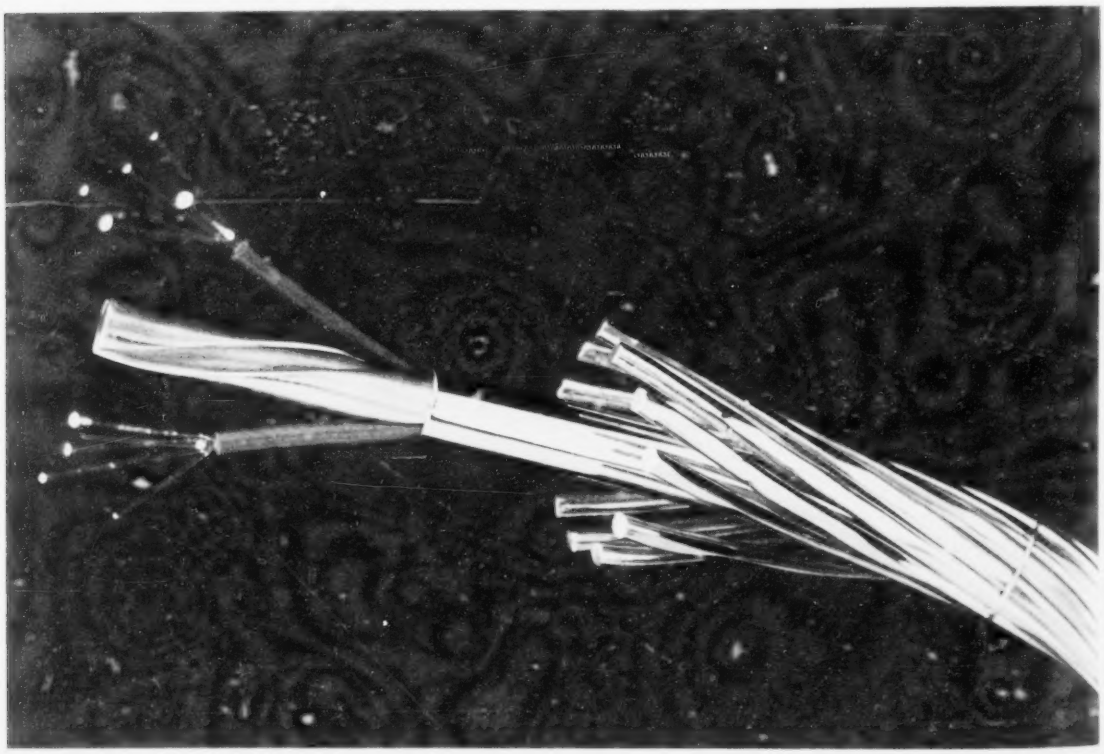
The Bureau has identified the clays commonly associated with oxidized copper deposits and is studying the effects these clays will have on in situ leaching of copper ores. Copper exchange capacities of clays such as montmorillonite, kaolin, and attapulgite are being determined. The data will be incorporated into a general in situ leaching computer model to determine the influence of clays on the overall recovery of copper.

Biotechnology offers a way to dissolve metals selectively in situ (without mining). The solution containing the dissolved metal is pumped to the surface where the metal is extracted.

Gallium and germanium recovery. Gallium and germanium are produced in relatively small quantities but have extremely important applications in modern technology. Applications of both gallium and germanium are critical to the rapidly growing electronics industry, and substitution cannot be made without substantial loss in performance in most cases. The demand for these metals will continue to increase over the next 5 to 10 years as new uses are identified and developed. Gallium compounds are used in laser diodes, microwave system components, photoelectrical materials, infrared telescopes, and light-emitting diodes. Gallium is also used in superconducting alloys, in gallium arsenide semiconductors, and in solar energy applications. Germanium was initially used in semiconductor devices such as transistors, diodes, and rectifiers, but recent applications have been in infrared and fiber optic systems.

Current domestic production of gallium and germanium is inadequate to meet the Nation's needs. Gallium and germanium production can be supplemented by processing low-grade deposits or developing methods to improve extraction from secondary resources. However, low germanium recovery has been a major problem when processing either low-grade ores or residues from zinc smelters and refineries. Bureau researchers are solving the low extraction from zinc residues problem by identifying the insoluble germanium phases and tailoring processing systems either to extract germanium from these phases or to avoid their formation. The zinc residues contain enough gallium and germanium to supply national needs, but are being stockpiled for sale overseas because technology is not available in this country to treat them economically. Developing methods to improve germanium extraction will encourage U.S. companies to process these residues domestically.

Acid-alcohol leaching of phosphate. More than 80% of the phosphate used for fertilizer in the United States comes from Florida's Bone Valley deposit. Current processing methods include beneficiation techniques in which about one-third of the phosphate contained in the ore is impounded as part of waste material. Because current phosphate deposits are declining in quality, and because there is about 75,000 acres of waste ponds, innovative methods to recover the phosphate from the discarded material would greatly increase the domestic reserve.



The Nation's fiber optic communications network depends on germanium supplies. Germanium is added to the outer surface region of the high-purity quartz fibers to change the index of refraction near the surface. This allows pulses of information that reflect off the sides of the fiber to travel at the same speed as those traveling along the axis, preventing distortion.

The Bureau's work in this area involves the selective extraction of the phosphate from the discarded material using sulfuric acid-methanol mixtures as the extractants. Sulfuric acid reacts with the phosphate-containing mineral to form the desired phosphoric acid product while the methanol suppresses the solubility of metal-containing impurities that otherwise might be coextracted. Phosphate extractions as high as 88% have been observed using this technique.

Bureau scientists have focused on two main objectives in this work. The first is to optimize the reaction conditions for achieving the highest possible extraction and selectivity. Metal impurities must be kept to a minimum if the phosphoric acid product is to be useful for making fertilizers. The second is to develop the most efficient technique for separating the acid product from the insoluble residue.

Graphite from kish. The United States is totally dependent on foreign countries for its supply of graphite, and is vulnerable to economic or political changes that might occur in China, Brazil, or Madagascar, which supply most imports.

Total annual imports amount to a relatively small 50,000 tons, but graphite is of critical importance to vital industries. In transportation, graphite is used in brake and clutch linings and in lubricants. Almost all small appliance and automotive electric motors use graphite brushes. Dry cell batteries require graphite. The iron and steel industry uses graphite for refractories, crucibles, and foundry facings. For these reasons, graphite has been classified as a strategic and critical mineral.

The Bureau has determined that a large domestic resource for graphite may exist in the form of a waste material called kish. Kish is a mixture of iron, graphite, and slag that is skimmed from molten iron before the iron is used for steelmaking. It is a nuisance waste that is usually buried. Bureau researchers have collected kish from several steel plants and run bench-scale tests that indicate the waste may be a source of graphite with quality equal to or better than imported natural graphite.

The next step in the research is to run larger scale continuous tests that will determine if a full-scale treatment process is feasible and if the product is a suitable substitute for natural graphite. If the feasibility tests are successful, a previously unsuspected resource for graphite will have been proven, and it will be possible for the United States to become self-sufficient in this important commodity.

Removal of heavy metals from liquids. A technique being developed by the Bureau appears to offer an economical answer to the problem of recovery and separation of metals from dilute mineral processing streams. This technique uses solvent extraction reagents in a surfactant-stabilized, liquid emulsion membrane (LEM). It offers potential advantages over conventional contaminant removal technologies because it has both selectivity of removal of individual contaminants, and a much higher efficiency of removal of the contaminant. The solution appears to have millions of tiny bubbles, which can be thought of as waste magnets, that selectively attract a particular ion. Preliminary tests have shown that this approach can remove 95% of the copper contained in a dilute stream. Other systems can be created to selectively remove different hazardous wastes.

Liquid emulsion membranes are fine bubbles filled with a solvent extractant. Dissolved metals diffuse through the bubble "skin" into the enclosed solvent. The bubbles rise to the surface, where they are skimmed off and broken, leaving the metal-rich solvent ready for metal recovery.

The basic approach is to mix a stripping (trapping) solution into an organic phase that contains a solvent extraction agent and surfactant to help stabilize the system. The LEM is contacted with the dilute solution, and the metal ions are trapped by the stripping solution. The metal-loaded solution is separated from the cleaned aqueous solution. The metals can then be recovered from the LEM solutions for recycling, and the clean LEM solutions can be reused on more waste products.

Materials Research

Materials research accomplishments are presented in three subdivisions: synthesis, processing, and characterization. The Bureau's materials research program involves cutting-edge technology and often is in the forefront of advanced developments. Bureau researchers are encouraged to be innovative and pioneering in their efforts to conduct the long-range, generic materials research required to make better use of our domestic resources and improve the national economy.

Synthesis. The new age of advanced materials is based, to a large degree, on the ability to synthesize complex powders and fibers from which the materials are to be made. The Bureau is studying a number of techniques, one of the more exciting being a plasma-microwave process, in which materials can be economically synthesized. This process has successfully demonstrated the synthesis of tungsten carbide, which is widely used in cutting tools, from tungsten and carbon. While conventional methods require 6 hours to synthesize the carbide, the Bureau's microwave-induced plasma method requires only 10 minutes to produce a commercial-grade material. Synthesis of other ceramic materials is being investigated, as is the basic process.

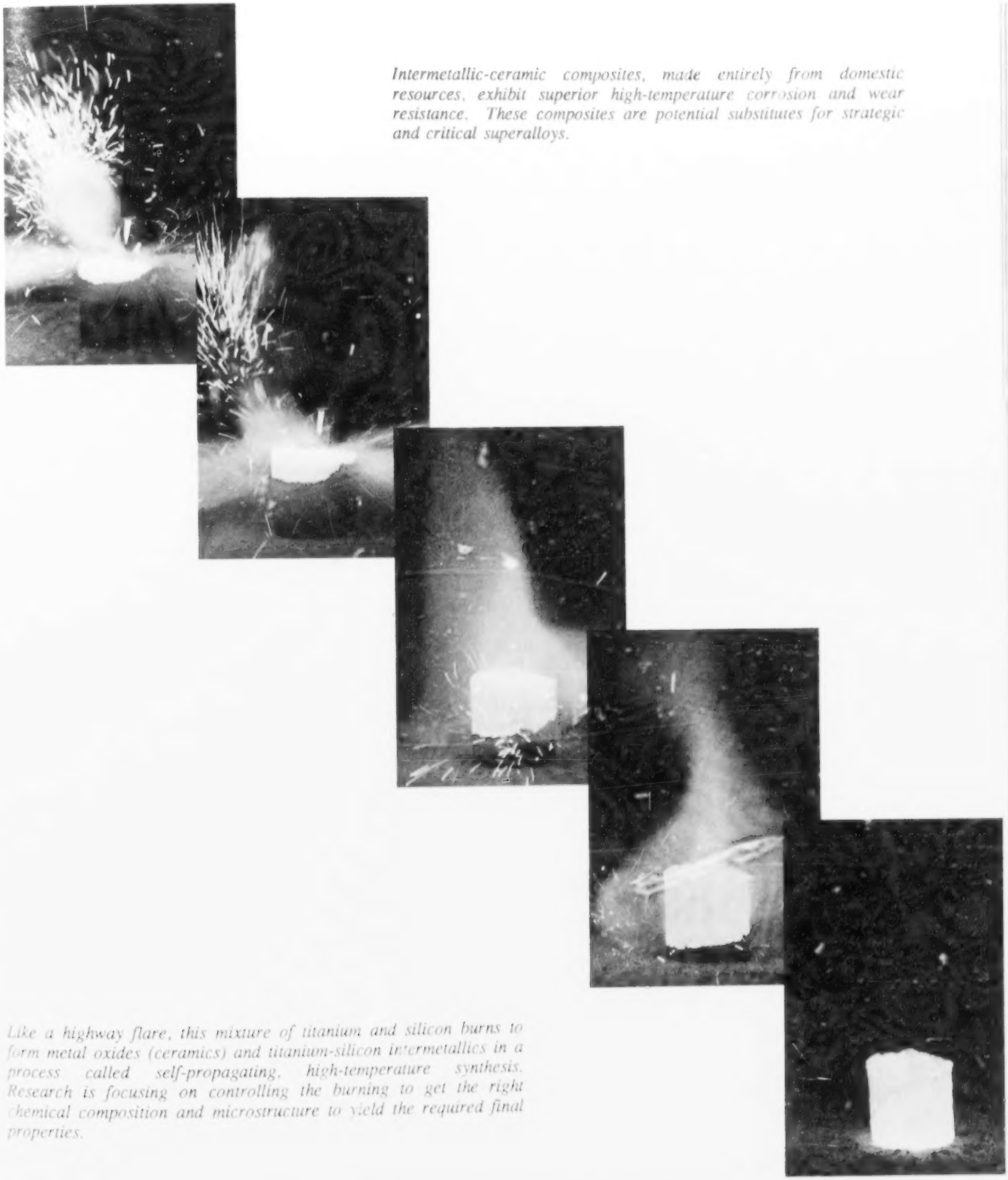
Processing. The principal efforts in materials research are related to innovative processing technology in which materials are fabricated from powders and fibers. The Bureau-developed turbomill has been highly effective in uniformly mixing these complex ceramic formulations. A new ceramic material made in this fashion from a mixture of titanium and aluminum nitrides and aluminum oxide, followed by high-temperature firing, consists of two microphases, a titanium-nitride, interspersed in an oxide spinel matrix. This new ceramic material, called tialon by the Bureau, can be made over an extensive range of compositions, and has exhibited excellent toughness properties, essential for consideration in high-stress applications. Toughness values have been two to three times those of commercial reaction-sintered silicon nitride with which Tialon is competing. Preliminary results have also indicated unique electrical properties depending on its titanium nitride content.

A tool for studying sintering behavior of ceramics is being investigated. This nondestructive technique consists of a pulsed laser that directs elastic waves on the ceramic surface during high-temperature sintering or densification of

Bureau scientist assembles attrition grinder to produce ultrafine ceramic powder for processing research.

Test samples of advanced ceramic materials are being inserted into a high-temperature isostatic press to study sintering behavior.

Intermetallic-ceramic composites, made entirely from domestic resources, exhibit superior high-temperature corrosion and wear resistance. These composites are potential substitutes for strategic and critical superalloys.



Like a highway flare, this mixture of titanium and silicon burns to form metal oxides (ceramics) and titanium-silicon intermetallics in a process called self-propagating, high-temperature synthesis. Research is focusing on controlling the burning to get the right chemical composition and microstructure to yield the required final properties.

the ceramic. The reflected waves are recorded with a piezoelectric sensor. Such factors as porosity, grain size, phase development, and defects can be detected and monitored. This tool can be useful not only for material studies but for assessing the quality of the materials being produced.

A technique for joining advanced silicon nitride ceramics, using silicon oxynitride glasses as a brazing agent, has been demonstrated as a way of producing large complex shapes from simpler, smaller pieces. Because physical properties decrease as pieces become larger, advantage can thus be taken of the ability to join smaller size pieces having superior physical properties to form a large piece with the same superior properties. Joints with mechanical properties comparable to those of the unbrazed ceramics have been achieved to temperatures as high as 1,100° C.

Research to conserve strategic and critical metals has resulted in a unique electrodeposition, heat-treatment method to produce complex, ternary metal coatings. The technology involves occlusion of suspended particles in an electrodeposited matrix. The Bureau's process of occluding chromium powders in an electrodeposited iron-nickel coating followed by a heat-treatment to convert the coating to stainless steel has been patented. This versatile process can be used to coat complex-shaped components, and when combined with a dissolvable substrate can produce thin-walled freestanding parts. Current research to better understand the fundamental processes of particle occlusion will enable application of this method to the development of advanced metal-matrix composite coatings and structures.

Unusual results have been achieved in producing stainless steel by novel rapid solidification processing techniques in which a sixtyfold increase in strength properties resulted. The strengthening is believed to be due to steels fine grain size as well as the small, stable gas-vacancy clusters in which fine dispersions of carbides form during aging. A number of iron-base alloys have been evaluated at temperatures up to 1,300° C and appear to offer advantages over conventionally produced alloys such as being stronger, lighter in weight, more resistant to higher temperatures, and able to survive longer service.

Significant progress has been made in developing the metal-joining technology needed to replace copper wire with much lighter weight aluminum wire in electrical and electronic applications. Aluminum is one-third the weight of copper, and uses exist where this factor is important, especially in automotive, aircraft, and space hardware where energy conservation is paramount. Building on the Bureau's strong soldering experience, a technique for economically applying very thin, continuous, nickel-copper coatings to aluminum wires, rendering them easily solderable, was demonstrated. The Bureau is studying the solderability of a number of advanced aluminum alloys as well as continuing its studies on the use of nontoxic zinc base solders for fabrication of copper-brass systems.

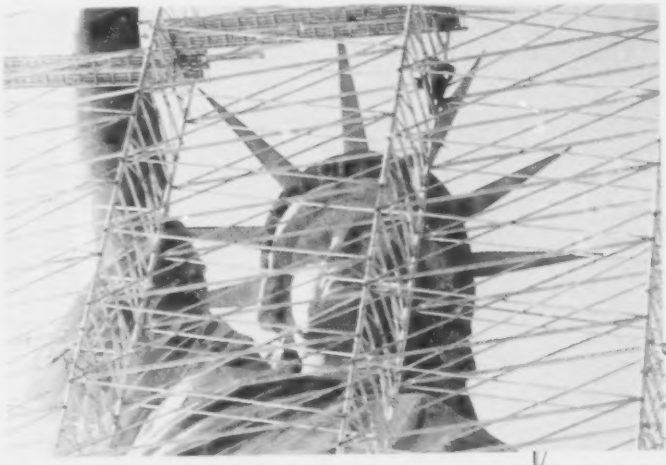
Characterization. Corrosion of materials is one of the more important problem areas that the materials research program addresses, as high corrosion losses are costly to the national economy. Basic corrosion data on the resistance of a number of ceramic materials to various acids were determined in order to optimize the selection of liner materials for chemical processing. Results indicated that carbon, followed by silicon carbide, silica, and fireclay were most resistant to hydrochloric acid; silica, followed by shale and fireclay, were most resistant to nitric acid; and high-alumina and carbon, followed by silica and silicon carbide, were most resistant to sulfuric acid. An accelerated autoclave test was developed in which results comparable to those attained in a 300-day conventional test were attained in 8 hours.

Another corrosion study, conducted in cooperation with a major aluminum company, involved the growth of corundum on the inside walls of furnaces used for aluminum recycling. A new test procedure was developed by the Bureau to assess the effect of refractory lining materials on the deleterious growth of the corundum, and a number of refractory materials were evaluated. Two solutions to this problem evolved; one by prior soaking of high-alumina refractory samples in a phosphoric acid solution, and the other by coating the refractory with a thin layer of spinel cement. Both solutions prevented corundum growth.

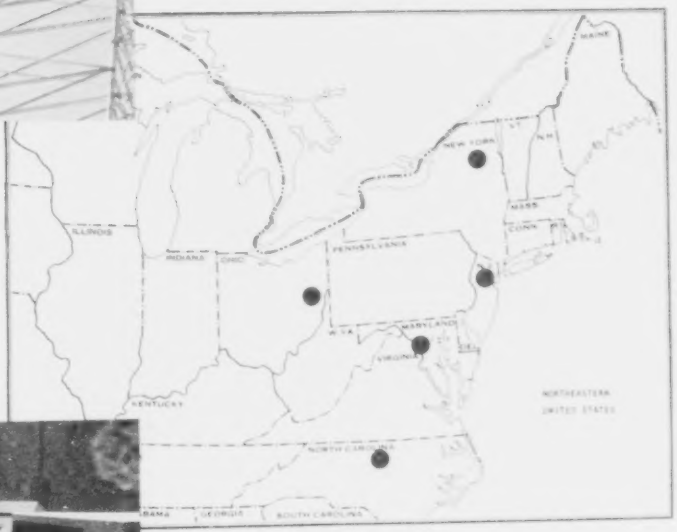
The Bureau has played a key role in the National Acid Precipitation Assessment Program since its inception in 1982, being responsible for measuring atmospheric corrosion damage to structural metals. In cooperation with the Environmental Protection Agency, tests have been conducted at five sites (North Carolina, Washington, DC, New Jersey, New York, and Ohio).

One of the Bureau's major materials research achievements in recent years has been the development of acid- and salt-resistant sulfur concrete. This was achieved by a scientific breakthrough in stabilizing the sulfur's crystal structure, resulting in a polymerized sulfur cement, used with natural aggregate to form concrete. Achievements in sulfur concrete have continued with the discovery that the addition of fiber-reinforcing materials could significantly reduce its shrinkage by as much as 50%, which enables larger, more complex shapes to be made.

Another discovery involved the addition of small amounts of carbon fibers to the sulfur concrete, resulting in its ability to conduct electricity, useful for cathodic protection and antistatic environments. Further research on sulfur concrete is continuing along a number of pioneering paths and cooperative efforts with other Federal agencies and industry are being pursued.



Atmospheric corrosion damages buildings and monuments. As the lead agency of metals corrosion in the National Acid Precipitation Assessment Program, the U.S. Bureau of Mines is working to distinguish the effects of "acid rain" from atmospheric corrosion.



Metal samples are exposed to the atmosphere at rural, industrial, urban, and coastal sites. Data from these sites will help to isolate different causes of corrosion.

Sophisticated analytical methods are used to identify corrosion products. Results will be used to develop better materials, define maintenance programs, and estimate impacts of regulations.

Samples are exposed for fixed periods of time, up to 5 years, in special racks according to ASTM standards.

Environmental Technology

The adverse ecological and environmental impacts caused by past mining and mineral processing operations and the concern of society about further detrimental impacts from present and future operations are among the most sensitive issues that confront the Nation's domestic mineral industries. Reflecting society's demands, local, State, and Federal agencies have introduced more stringent environmental regulations, and the industry has introduced more environmentally compatible waste management practices. However, much remains to be done both in cleaning up wastes produced from past operations when the environmental impacts were not recognized and in ensuring future beneficial use of the Earth's resources without causing irreversible damage to the land, waters, and wildlife, or endangering human health.

To help the Nation minimize the environmental impact of mining and mineral processing operations, the U.S. Bureau of Mines is developing new technology that addresses both the waste produced from past operations and waste from current operations. This research involves several major waste and environmental problems with priority areas including the treatment, detoxification, and safe disposal of solid wastes; control and mitigation of the effects of acid mine drainage from both coal and metal mines; mine fires; and subsidence abatement and prediction.

Hazardous wastes management. Wastes produced by the mineral industries account for 80% of the Nation's nonagricultural, land-disposed solid wastes. Probably the single most important characteristic of these wastes is that they often contain minerals that can be dissolved by contact with surface or ground waters to produce toxic heavy metal ions that can contaminate water resources. Fortunately, most of the 50 billion tons of waste that has accumulated from past mining operations and the 1 to 2 billion tons per year currently produced are of relatively low toxicity, but the sheer volume and diversity of the wastes pose a threat to the environment. In the West, for example, metal mining wastes may contain mercury, lead, arsenic, cadmium, selenium, and other metals that are toxic to aquatic and terrestrial natural life forms, including humans if assimilated in the food chain.

Recognizing this problem, State and Federal Governments are introducing increasingly stringent environmental and waste management regulations that affect active mining and mineral processing operations as well as facilities that are now closed or abandoned. The Resource Conservation and Recovery Act (RCRA), enacted in 1976 and amended in 1980 and 1984, and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) or Superfund, enacted in 1980 and amended in 1986, are among the largest regulatory programs ever undertaken by the Environmental Protection Agency (EPA). RCRA undertakes the regulation of all aspects the management of hazardous and solid waste from the time it is generated to final disposal and addresses current generators. CERCLA provides Federal authority to EPA to respond to the environmental hazards posed by abandoned or closed sites, and provides the resources for cleaning up these sites by holding companies responsible for the damage caused by past waste disposal practices.

Conventional approaches to mineral waste management cannot provide cost-effective, and in many cases, technically feasible solutions to meet regulations under RCRA or to correct, under CERCLA, the environmental damage caused by past practices. Moreover, under the statutory authority of RCRA, EPA is actively promulgating and implementing new regulations for identification and management of hazardous and solid wastes generated by the mining and mineral processing industries.

This uncertain and changing regulatory climate has led to equal uncertainties on the part of industries concerning what wastes will be classified as hazardous, and what acceptable waste management practices and technologies will be required in the future. These uncertainties inhibit industry from expanding operations, proceeding with new ventures, and even introducing new and better waste management practices for fear the new practices will not meet future regulatory requirements. For these reasons the Bureau, under a newly formed Division of Environmental Technology, is developing new technologies that take into account site- and waste-specific factors that can lead to air and water pollution, or land contamination. This research (1) will ensure that the wastes generated now and in the future will be less toxic and of a lower volume than those generated in the past, or (2) will be disposed of with methods that render the toxic constituents immobile in the environment.

Metal contamination of soils and water supplies is the major environmental problem associated with mining and mineral processing wastes and is the priority focus of the Bureau's research on hazardous wastes. The problem of metal-bearing wastes is not just a mineral industry concern. Metals contaminate over half of the sites on the National Priorities List published by EPA as a part of its Superfund responsibilities.

The detoxification of metal-bearing wastes is nearly analogous to the major objective of most metal mining operations; the economic extraction and recovery of metal values from low-grade ores. Thus one focus of the Bureau's hazardous

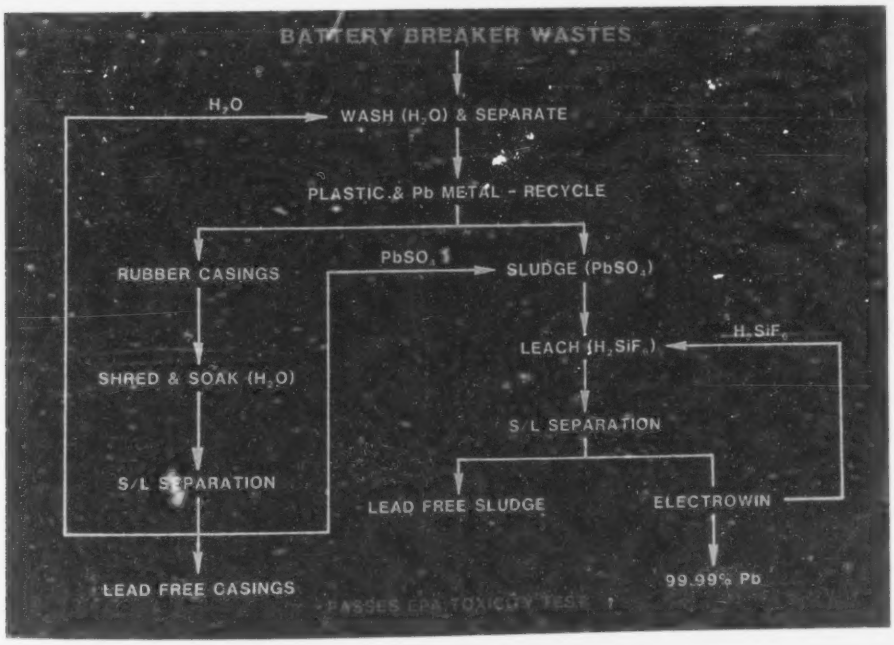
Waste from lead-acid batteries.

waste research is to utilize its expertise in extractive metallurgy to remove toxic metals from mineral wastes and from contaminated soils and waters. In most cases, however, applying today's metallurgical technology to existing wastes is not an economically viable solution. Mine and mill rejects are wastes because they could not be economically processed to recover residual metals. Therefore, existing technology must be modified and extended to treat wastes containing relatively low, but toxic, metal components or entirely new technology must be developed to detoxify these wastes. In some cases, it is anticipated that modified or new technologies may be introduced as unit processes into current process streams. This will greatly reduce the volume and toxicity of any wastes generated in the future.

The Bureau is looking at a number of modified extractive metallurgy technologies for potential applications to waste detoxification. One outstanding example is the IR-100 award-winning technology developed by the Bureau for removing and recovering lead as a product from soils that have been contaminated at sites where lead-acid batteries were recycled. There are numerous such sites in the country; 17 have already been placed on the National Priorities List of Superfund sites by EPA, and 16 other sites are proposed for listing.

The process developed includes two operations: recovery of lead metal from battery posts and grids, and treatment of battery sludge and contaminated soil for lead recovery. Lead is present in the soils as oxides or sulfates and is converted to lead carbonate and then leached with dilute fluosilicic acid. The lead is recovered by electrowinning. The soils are then treated with nitric acid and filtered, resulting in a detoxified, or lead-free, soil product. EPA is now funding the Bureau to scale up this research for the eventual construction of a pilot plant.

Another major thrust of the Bureau's Environmental Technology Program involves the use of biotechnology for mine waste management. It is well known that bacteria can change the form and mobility of metals. In fact, the mineral



Flowsheet for processing battery breaker wastes.

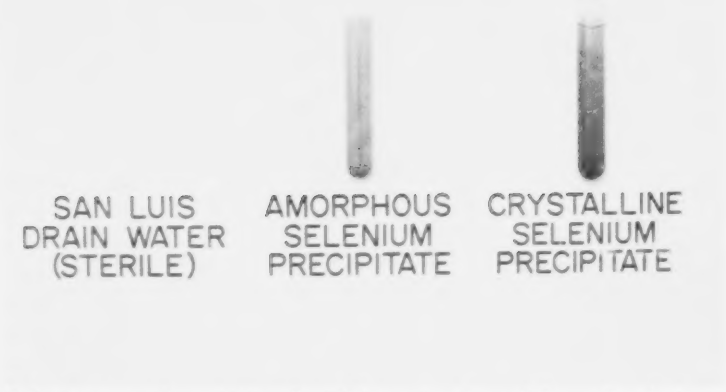
industry has used this knowledge in heap and dump leaching operations where bacteria actually participate and accelerate the dissolution of metals from ores. More recently, industry has begun to use a biotechnical process for converting cyanide used in gold heap leaching operations to benign constituents for safe discharge of process waters. Industry is also adopting Bureau-pioneered "engineered wetlands" that utilize a host of complex biological processes that are not fully understood to neutralize acid mine drainage waters from coal mines.

Bacteria operate on metals through bioleaching, biosorption, and bioreduction mechanisms and Bureau scientists are attempting to exploit each of these mechanisms for detoxifying wastes. Biosorption and bioreduction are most applicable to contaminated waters. Promising laboratory research in these areas are expected to advance to the field demonstration stage within 1 or 2 years. An example is a newly developed technique to immobilize dead biota (yeast, fungi, algae) in porous plastic beads. The thermally killed biota are selective for particular metal ions and immobilization in polymers provides a method to physically remove and possibly recover metal values after the ions adsorb on the active bacteria sites. Other research has shown that bacteria can be cultured from selenium-containing waters. These bacteria will reduce toxic selenates to crystalline metal selenium that can be separated from waste waters. This research may have application to the selenium-containing drainage waters from the San Joaquin Valley, in addition to applications to mine and mill waters containing selenium.

Scientists believe that bacterial processes may provide effective waste management techniques because these processes work well when metals are present in low concentration, are often self-initiating and effective when appropriate nutrients and conditions are maintained, and they can be introduced without major capital costs. In some cases this approach may provide long-term waste management without the prohibitive long-term maintenance costs.

Scientists are also trying to gain a better understanding of the environmental threat presented by mineral wastes, particularly with respect to how toxic metals are released from mine and mill wastes. The Bureau is looking at fundamental reaction mechanisms and factors that determine how metal ions dissolve, how they migrate through water and soil, and how they may be complexed, removed, or converted to benign chemical forms. Two important aspects of this work are field studies to develop sampling techniques for realistically characterizing wastes and laboratory studies, conducted in column cells, designed to determine how metal ions are leached from the wastes and the important variables that control the dissolution process. This work should provide a basis for developing risk assessment models that can be used to predict the hazards presented by particular wastes and that take into account waste- and site-specific factors.

The Bureau's work on waste management technology can benefit not only the mineral industries but other groups tasked with handling toxic wastes. The Bureau has signed cooperative agreements with EPA, other Federal agencies, and State environmental organizations to ensure that these groups have access to the Bureau's expertise and to the results of the research in this area. The Bureau also encourages industry participation in areas that are broad enough and can have a beneficial impact on significant National and State problems. Two examples are the ongoing cooperative studies with a consortia



Selenium metal precipitated with bacteria cultured from San Luis drain water.

Obtaining core samples and installing monitoring wells at abandoned metal mine tailing sites.

of gold heap leaching operators and the cooperative studies with individual Alaskan placer miners. The purpose of the consortia studies is to determine how cyanide used in the heap leaching process reacts with soils. The cooperative studies with the placer miners is to to demonstrate new Bureau-developed technology to remove suspended solids from process streams to levels that are required by Federal or State regulations.

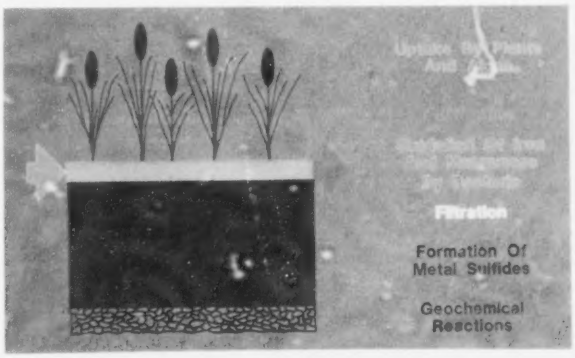
Acid mine drainage. Contaminated mine drainage is one of the most persistent problems in the United States. According to a recent inventory, over 7,000 miles of rivers and streams is adversely affected by coal mine drainage, mostly from mines that have been abandoned for many years. The impact would be even greater except for the fact that mines that have been active since 1978 chemically treat their effluent water, at a total cost of over a million dollars a day. Much of the Bureau's research is therefore directed to the development of less expensive alternatives to chemical treatment, as well as control methods appropriate for abandoned mines.

One approach that has proven to be useful at both active and abandoned mines is biological water treatment, using wetlands constructed for that purpose on the mine property. Metals are precipitated and acidity is neutralized by biological activity, with iron- and manganese-oxidizing bacteria and sulfate-reducing bacteria playing significant roles. The Bureau is now investigating the possible extension of this biotechnology to metal mine drainage.

Another approach is to improve the ability to predict future acid mine drainage problems. The Bureau evaluated methods that are used to predict postmining water quality and found them to be very inaccurate. To improve such predictions, and thereby prevent problems in the future, the Bureau is conducting basic geotechnical research in surface and underground mines. Other studies are addressing the techniques to accelerate acid production to prevent the need for long-term water treatment.

Acid mine drainage

Wetlands process



Engineered wetlands for neutralizing acid waters from abandoned and active coal mines.

Wetlands

Fires on abandoned mine lands. Across the United States there are hundreds of mines and old coal refuse piles that are on fire. These fires emit gases that affect the health and safety of local residents and pose a constant threat to property. The States and the Office of Surface Mining, Reclamation and Enforcement (OSMRE) are currently spending hundreds of millions of dollars in attempts to extinguish many of these fires. However, they are hampered by the difficulty of assessing the underground extent of the fires and the lack of effective extinguishment techniques other than complete excavation of the fire, which is expensive and sometimes destructive of those same surface properties that were originally threatened.

The Bureau's approach to this problem has been twofold. First, new diagnostic techniques have been developed to allow the accurate delineation of the fire zone(s) and to monitor the progress of fire extinguishment efforts. Single-borehole measurements of temperature and gas composition have been replaced by a borehole-network technique that samples the mine atmosphere from widespread areas of the mine. In addition, the Bureau has established fire signatures in the mine atmosphere that can be related to the temperature of the coal, thus indicating the presence and/or absence of heated coal. Field tests conducted in cooperation with OSMRE have demonstrated the effectiveness and practicality of this new approach to diagnosing underground mine fires. The Bureau is attempting to extend this technology to burning coal refuse piles.

The second approach to the problem is extinguishment. The Bureau is evaluating two new heat-removal concepts: the use of cryogenic inert gases, such as liquid nitrogen, to extinguish a burning coal refuse fire and foam injection, fume exhaust for remote extinguishment of an underground mine fire. This latter concept will be field tested in cooperation with the Pennsylvania Department of Environmental Resources at a site south of Pittsburgh, after the Bureau's diagnostic work has successfully delineated the extent of the fire.

Mine subsidence. The collapse of the ground following the removal of minerals from underground mines can cause catastrophic damage to the land and surface structures in the areas above the mines. The vast majority of the subsidence problems occur above coal mines, although there also are serious problems in cer-

Coal refuse pile fire.

tain coal mining areas of the country. In room-and-pillar mines, large pillars of coal are left unmined to support the Earth's surface. In time, however, the earth above the mines or overstressed floors underneath the supporting pillars crack and fail, leading to subsidence in the immediate mined-out area.

The surface over total extraction mining (e.g., longwall coal mines) may begin subsiding immediately as mining proceeds. Typical longwall coal mine panels vary from 500 to 900 feet in width and run as much as a mile long. Not only does subsidence cause devastating damage to surface structures above these longwall mines, but in the State of Illinois alone, changing ground water levels and drainage patterns threaten to make hundreds of thousands of acres of prime farmland less productive.

Because mining and farming both contribute substantially to the economy of Illinois, the two industries cooperate and have asked the Bureau (and several State agencies as well) to assist them in their efforts to improve methods used for mining coal while minimizing the impact to farming in the area. Cooperative research programs being conducted by the Bureau and several state universities are directed toward developing better understanding of the technologies being used for forecasting the location, magnitude, and affected area of subsidence events. Research also is being concentrated in the measurements of horizontal and vertical ground movements, the stresses these movements induce on surface structures, and changes in near-surface ground waters.

The Bureau is continuing to improve the two subsidence prediction models it has developed. One model was patterned after popular European empirical methods but was altered using a novel variable subsidence coefficient in order to be applicable to geological conditions that exist for longwall operations in the northern Appalachian Coal Basin. A computer program was written for this model capable of being used on personal computers. Copies of this program were distributed to mining companies operating in the region and are currently being used by them in planning their mine designs. Current research is investigating this model's applicability to the southern Appalachian region. The Bureau's second subsidence prediction model is based on an analytical approach, capable for use in room-and-pillar operations. This model can also be used for longwall coal operations and its applicability is being tested on mining operations in Illinois.

The Bureau is continuing to study the relationship between subsidence and ground water conditions by monitoring well-water levels over longwall operations. Sufficient data are needed in order to determine the influence that topography, geology, and hydrology have on water level changes.

Effect of subsidence above a longwall panel.

Information and Analysis

The Bureau of Mines, as the chief U.S. Government minerals information source, regularly collects statistics on domestic mineral production, stocks, and consumption on approximately 100 mineral commodities. The Bureau also receives national production reports from approximately 160 foreign governments and official trade statistics from U.S. and foreign agencies.

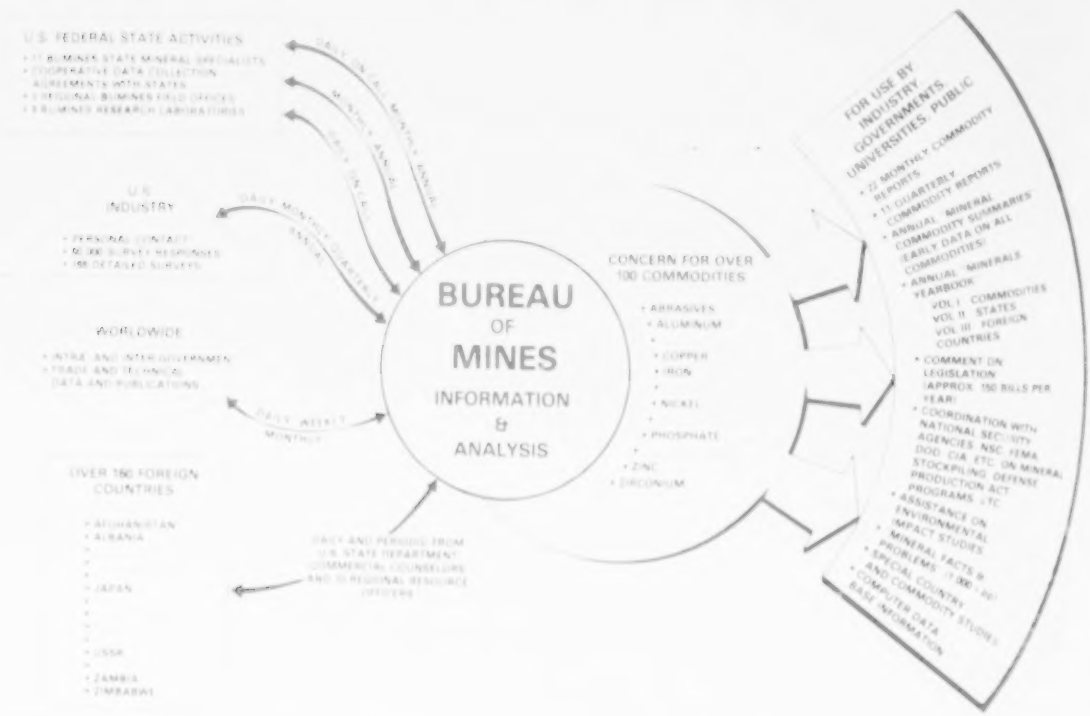
The Bureau analyzes a wide range of issues affecting the availability of minerals and the economic health of U.S. mineral producers, and it maintains programs involving land assessment, minerals availability, and State mineral activities. Information from these programs, the commodity and country specialists, and other domestic and foreign sources provide the groundwork for mineral availability studies, regional minerals assessment reports, regulatory analyses, and other policy studies.

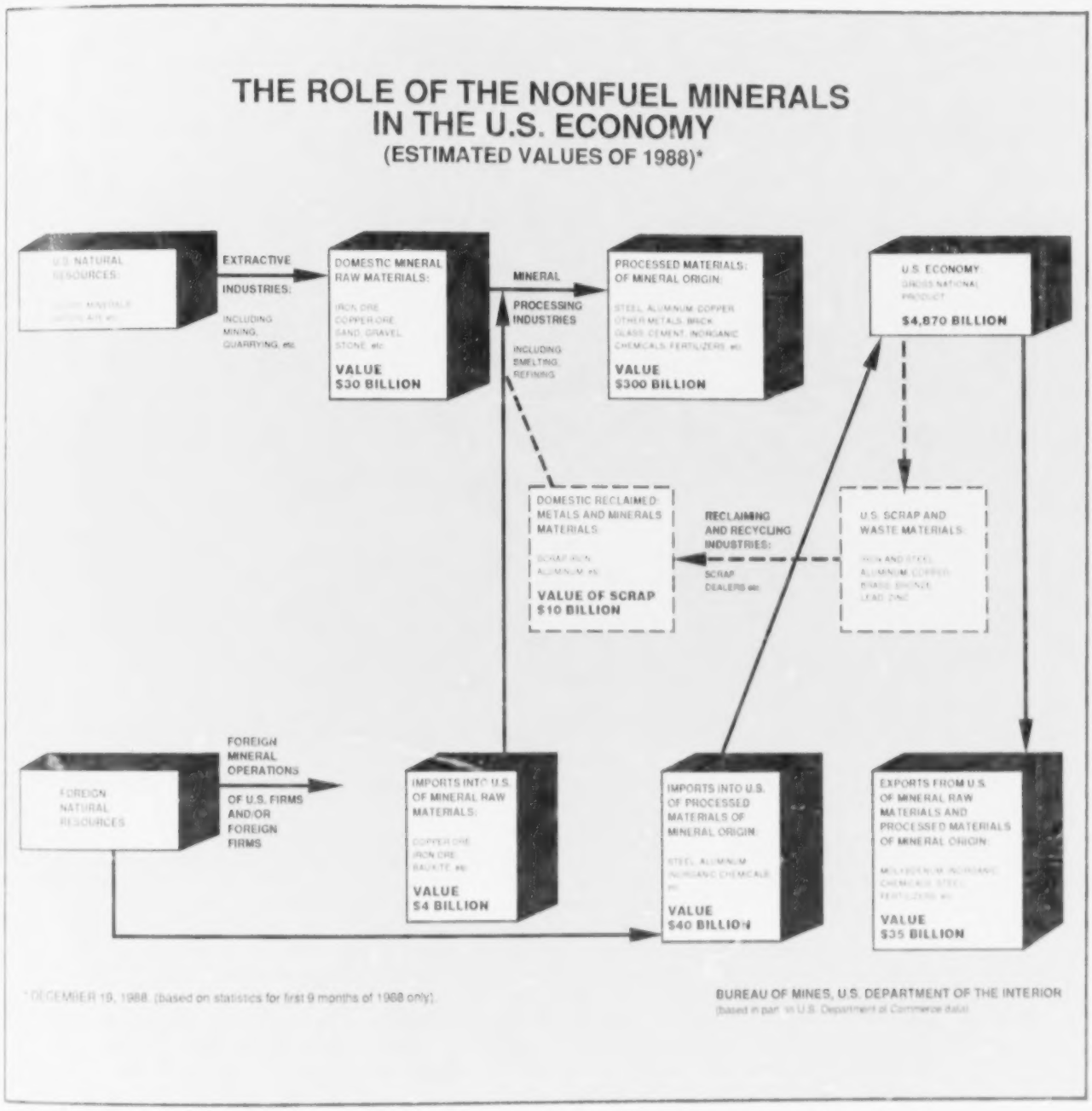
Commodity and country specialists of the Bureau constitute a unique body of minerals expertise not only in the Government, but in the country at large. They are world-class experts in minerals production, supply, demand, current development, and emerging trends. Their advice is sought in policy development and in the evaluation of mineral market opportunities.

Information and analysis activities include responsibilities to assess the current and potential supply of minerals. The land assessment studies respond to land use planning needs of other Federal agencies and Indian tribes. The minerals availability component provides the Federal Government with a unique base of deposit-specific geological, production cost, and economic data to support studies of current and future mineral supplies.

Among the Bureau's analytical responsibilities, none is more important than evaluating the current conditions and future prospects of the minerals sector of the economy. Minerals required to maintain our high standard of living, a quality environment, and a strong national defense are often taken for granted. Our transportation depends on vehicles made of iron, steel, aluminum, copper, lead, and zinc. Roads and buildings require sand, gravel, limestone, and clays. Everyday electronic devices such as computers, televisions, telephones, photocopiers, and even the automatic doors and cash registers at the supermarket could not operate without copper, gallium, germanium, or silicon.

The Bureau participates in the public policy decisionmaking process to help assure that the minerals the American consumers need in the course of their everyday lives are available to them now and in the years to come.


U.S. FEDERAL STATE ACTIVITIES
U.S. INDUSTRY
WORLDWIDE
OVER 160 FOREIGN COUNTRIES
BUREAU OF MINES INFORMATION & ANALYSIS
CONCERN FOR OVER 100 COMMODITIES
• ABRASIVES
• ALUMINUM
• COPPER
• IRON
• NICKEL
• PHOSPHATE
• ZINC
• ZIRCONIUM
FOR USE BY INDUSTRY, GOVERNMENTS, UNIVERSITIES, PUBLIC
• 12 MONTHLY COMMODITY REPORTS
• 11 QUARTERLY COMMODITY REPORTS
• ANNUAL MINERAL COMMODITY SUMMARIES (EARLY DATA ON ALL COMMODITIES)
• ANNUAL MINERALS YEARBOOK
VOL I COMMODITIES
VOL II STATES
VOL III FOREIGN COUNTRIES
• COMMENT ON LEGISLATION (APPROX 150 BILLS PER YEAR)
• COORDINATION WITH NATIONAL SECURITY AGENCIES (NSC, FEMA, DOD, CIA, ETC.) ON MINERAL STOCKPILING, DEFENSE PRODUCTION ACT PROGRAMS, ETC.
• ASSISTANCE ON ENVIRONMENTAL IMPACT STUDIES
• MINERAL FACTS & PROBLEMS (300-60)
• SPECIAL COUNTRY AND COMMODITY STUDIES
• COMPUTER DATA BASE INFORMATION


THE ROLE OF THE NONFUEL MINERALS
IN THE U.S. ECONOMY
(ESTIMATED VALUES OF 1988)*
U.S. NATURAL RESOURCES:
EXTRACTIVE INDUSTRIES:
INCLUDING MINING, QUARRYING, etc.
DOMESTIC MINERAL RAW MATERIALS:
IRON ORE, COPPER ORE, SAND, GRAVEL, STONE, etc.
VALUE $30 BILLION
MINERAL PROCESSING INDUSTRIES
INCLUDING SMELTING, REFINING
PROCESSED MATERIALS OF MINERAL ORIGIN:
STEEL, ALUMINUM, COPPER, OTHER METALS, BRICK, GLASS, CEMENT, INORGANIC CHEMICALS, FERTILIZERS, etc.
VALUE $300 BILLION
U.S. ECONOMY
GROSS NATIONAL PRODUCT
$4,870 BILLION
DOMESTIC RECLAIMED METALS AND MINERALS MATERIALS:
SCRAP IRON, ALUMINUM, etc.
VALUE OF SCRAP $10 BILLION
RECLAIMING AND RECYCLING INDUSTRIES:
SCRAP DEALERS etc.
U.S. SCRAP AND WASTE MATERIALS:
IRON AND STEEL, ALUMINUM, COPPER, BRASS, BRONZE, LEAD, ZINC
FOREIGN NATURAL RESOURCES
FOREIGN MINERAL OPERATIONS OF U.S. FIRMS AND/OR FOREIGN FIRMS
IMPORTS INTO U.S. OF MINERAL RAW MATERIALS:
COPPER ORE, IRON ORE, BAUXITE, etc.
VALUE $4 BILLION
IMPORTS INTO U.S. OF PROCESSED MATERIALS OF MINERAL ORIGIN:
STEEL, ALUMINUM, INORGANIC CHEMICALS, etc.
VALUE $40 BILLION
EXPORTS FROM U.S. OF MINERAL RAW MATERIALS AND PROCESSED MATERIALS OF MINERAL ORIGIN:
MOLYBDENUM, INORGANIC CHEMICALS, STEEL, FERTILIZERS, etc.
VALUE $35 BILLION
*DECEMBER 19, 1988. (based on statistics for first 9 months of 1988 only).
BUREAU OF MINES, U.S. DEPARTMENT OF THE INTERIOR
(based in part on U.S. Department of Commerce data)

The minerals required to maintain our high standard of living and defend our country are often taken for granted. The value of processed materials of mineral origin produced in the United States is roughly 10 times that of domestic raw materials, contributing substantially to the nearly $5 trillion U.S. gross national product.

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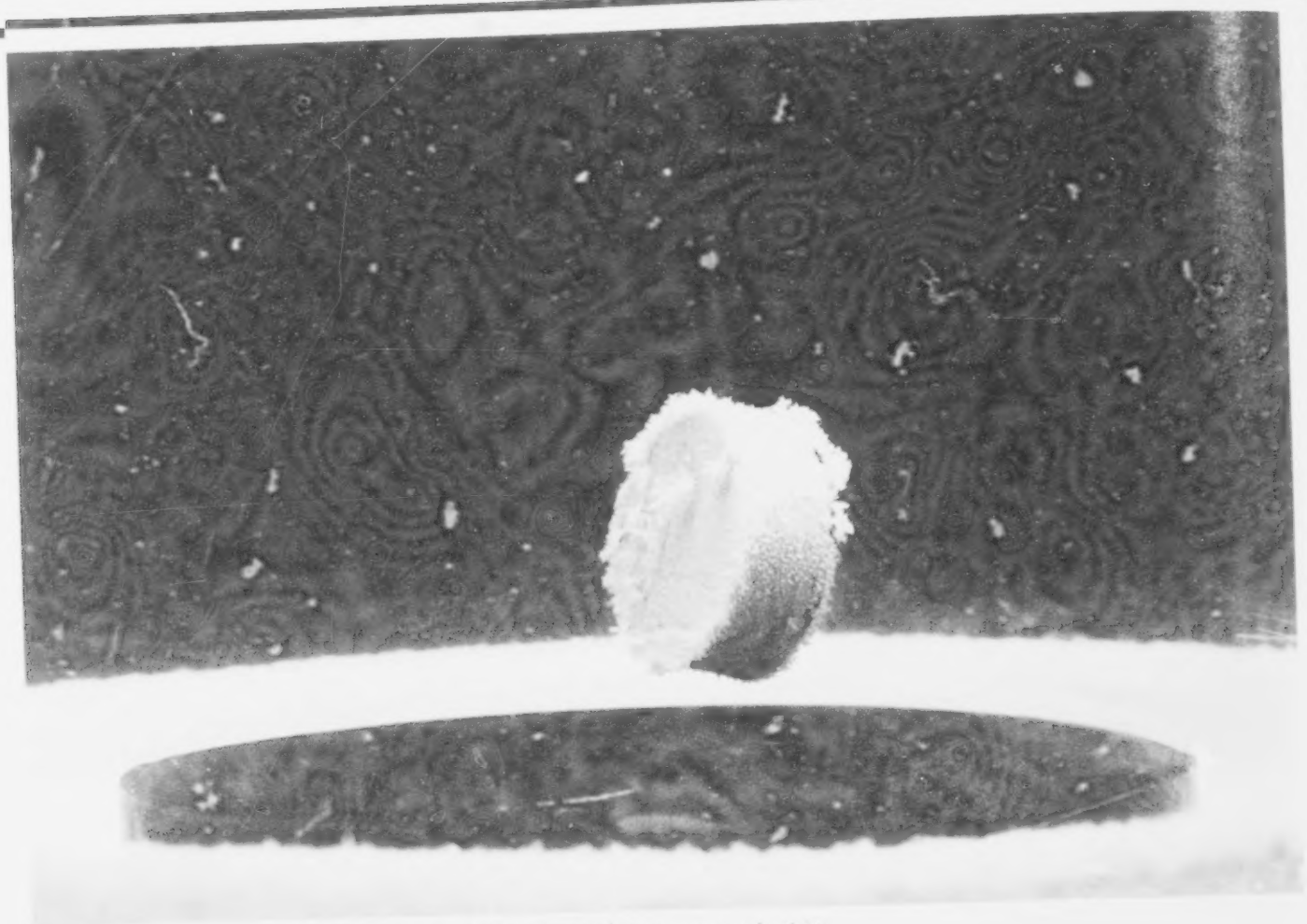


The Bureau is conducting research into superconductivity.

Advanced Materials

The Bureau's Office of Advanced Materials Coordination (OAMC) interrelates activities in policy support studies to prepare market forecasts, international policy comparisons, and special impact statements; makes materials systems evaluations to consider total life-cycle costs of competing materials; and has identified surface science, processing science, new materials synthesis, advanced materials joining, recycling, and materials competition as the advanced materials areas in need of investigation.

OAMC contributed to the National Critical Materials Council's Advanced Materials Program Plan and participated in the Committee on Materials of the Office of Science and Technology Policy in the Executive Office of the President, subcommittees on superconductivity, advanced ceramics, and nondestructive evaluation, and an interagency materials group.

Bureau researchers have sought to identify materials linked to the continuing evolution of high-technology fields (e.g., electronics, catalysis, and energy) that have limited domestic availability but are not stockpiled. The Bureau has identified 14 materials meeting these criteria: cesium, gallium, hafnium, indium, osmium, rhenium, rhodium, rubidium, ruthenium, scandium, selenium, tellurium, thallium, and zirconium. Researchers assessed the potential criticality of these materials by considering end uses, demand trends and forecasts, production, mineral reserves, byproduct status, alternative supply sources, substitution and conservation options, and recyclability.

The Bureau's commodity specialists studied the technology, end uses, materials availability, and potential development aspects of gallium, strontium, and ultra-high-purity silicon. All of these materials are designated as critical materials by the Department of Defense.

Bureau analysts also studied the disposition of superalloy scrap in 1988. This work was performed in cooperation with the U.S. Air Force. Because military aircraft are composed of substantial quantities of superalloys, particularly in jet engines, it is important to be able to gauge the domestic availability of superalloy scrap. The results of the Bureau's research showed that of the 55 million pounds of superalloy scrap processed in 1986, 92% remained in the United States for domestic reprocessing while 7% to 8% was exported. Of the 50 million pounds of scrap remaining in the United States, 70% was remelted into the same form of superalloy, 20% was remelted into another high value superalloy, and only 10% found its way into minor constituents of other metals. The average content of superalloy scrap was found to be 44% nickel, 16% chromium, 2% columbium; manganese, tantalum and rhenium were present in very small quantities, less than 1%, while aluminum, iron, molybdenum, titanium, tungsten, and others were present as minor constituents in the superalloy scrap.

Finding of previously unknown mineralization in southeastern Alaska resulted in the discovery of high-grade gold ore in the Chilkat Mountains.

Resource Evaluation

Location of high-grade gold occurrence in Alaska Mining District. The Bureau is assessing the mineral resources of Alaska, in part by studying the mining districts under a district studies program designed to systematically examine, in cooperation with the State of Alaska, all the State's public lands.

While conducting the Juneau mining district studies, field crews discovered an area of mineralization in rock formations not usually considered to be mineralized. The area of previously unreported mineralization is about 20 miles south of the city of Haines, and about 3 miles west of Lynn Canal. Initial publication of the discovery in a news release resulted in immediate claims staking activity at the site, and a private company is currently involved in exploring the occurrence. Initial assay values showed as much as 3.5 ounces gold per ton, 7.3 ounces silver per ton, 2.1% copper, and small amounts of zinc and cobalt. Average U.S. gold ores assay about 0.1 ounce per ton, and ores containing significantly less gold can be mined profitably. The Bureau is doing work to further delineate the mineralized area.

The discovery was one of several that have been made during the course of the 4-year study of the mineral resources of the Juneau mining district. A similar district study is being conducted on the Valdez Creek mining district, between Anchorage and Fairbanks.

Statewide mineral deposits and infrastructure in Alaska. U.S. Bureau of Mines researchers compiled and related information on the most promising mineral deposits in Alaska to the Alaskan State infrastructures critical for mineral development. The Bureau also considered institutional factors such as State mineral taxes and regulations. A primary goal of this study was to present information in convenient form to the lay public on some of the diverse factors affecting Alaska's mineral development potential. The results of this study have been published as Information Circular (IC) 9177.

The report summarizes mining activity in Alaska, State regulations, taxes, and mineral development incentives. Existing energy and transportation infrastructure necessary to mining activity are depicted. The core of the report consists of data abstracts on 67 principal deposits that appear to have commercial production potential. Each data abstract identifies the location of the mineral deposit, ownership, geology, and factors relating to the development history and site developmental requirements for water, power, and roads. A history of published reserve-resource estimates as well as a comprehensive list of references for each deposit are also included. In addition to these 67 deposits, an appendix lists 214 other important, but lesser known deposits that do not have published resources, yet may be of equal or greater commercial potential. This list contains the deposit name, map number, mineral commodities, and bibliographic

The Centennial Mountains, astride the Idaho-Montana border, are the locale of many mineral occurrences being categorized in data abstracts for States with important mineral potential.

references. The locations of all 281 mineral deposits are shown on a foldout map.

This report is the second in a series on States with important mineral potential. A similar report has been completed for Nevada (IC 9035), and reports for Arizona, Idaho, and Montana are in preparation.

Mineral assessments and public land use. The Bureau, in cooperation with the U.S. Geological Survey (USGS), has been evaluating mineral resources within the California Desert Conservation Area since 1980. The Federal Land Policy and Management Act (FLPMA) of 1976 specifically requires that mineral surveys be performed on Bureau of Land Management areas to be recommended for wilderness designation.

In 1987, the California Desert Protection Act was introduced as Senate bill 7. This proposed legislation would designate 115 wilderness areas with a total of 8.8 million acres. The Bureau and USGS have conducted studies under provisions of FLPMA on about one-third of the areas included in the bill. A mineral resource briefing report on this pending legislation was prepared for use by Congress and the land managing agency in order for them to make informed decisions. Data on the areas not previously studied were obtained by utilizing mineral information in available reports and maps.

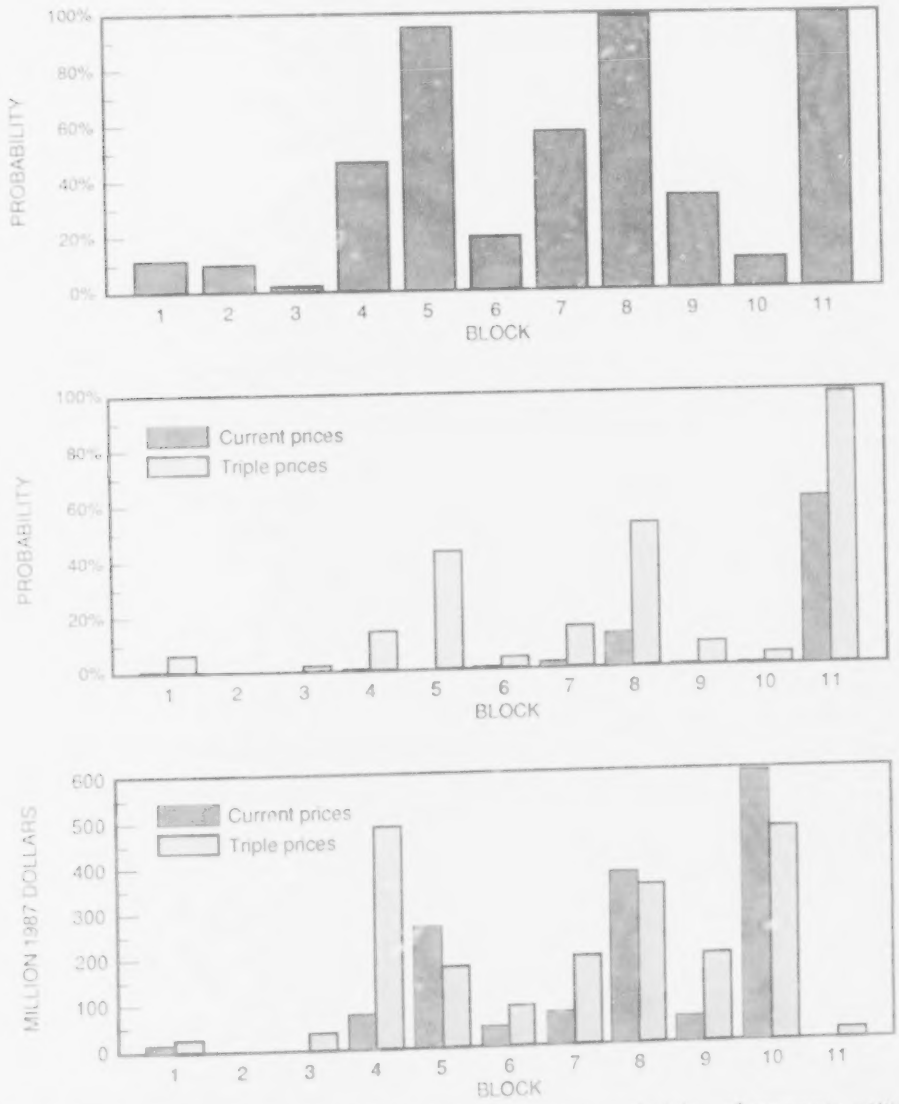
Many of the proposed wilderness areas studied contain or are expected to contain a variety of minerals important to our Nation's economy, security, competitiveness, and balance of trade. Because of the concern about the supply of these minerals and the abundance of known and potential minerals in the California Desert region, the Department of the Interior has opposed enactment of the bill.

Three widely differing Nevada wilderness bills were introduced in the 100th Congress. Briefings were held by the Bureau and USGS with congressional staffs, and personnel from the Department of the Interior and Forest Service

The Bureau identified areas of known gold, silver, and tungsten mineralization, and areas of high concentrations of mining claims, which resulted in the exclusion of approximately 72,000 acres from a proposed 100,000-acre wilderness withdrawal.

concerning the importance of minerals in many of the proposed wilderness withdrawals. The final 1988 markup bill in the House of Representatives (H.R. 2142) recommended a total of about 730,000 acres in 14 separate areas. Mineral data provided by the U.S. Bureau of Mines identified areas of known mineralization (including gold, silver, and tungsten) and high concentrations of mining claims. Taking this information into account, decisionmakers reduced the size and/or modified the boundaries for 8 of the final 14 areas. For example, the approximately 100,000-acre Grant Range roadless area of the bills introduced was reduced to approximately 28,000 acres to exclude large portions of the mineralized lands.

Potential mineral supply from undiscovered deposits in the Steese-White Mountain Region of Alaska. Using the potential supply analysis system, the Bureau estimated the mineral impacts of proposed resource management plans for Bureau of Land Management (BLM) administered lands in Alaska. The analysis, performed for the BLM Steese-White Mountains District Office, estimated the quantities of undiscovered minerals in the White Mountain National Recre-



The Bureau determined the probability of existence (top), probability of economic activity (middle), and average net present value of undiscovered mineral deposits in 11 geographic blocks of a BLM-administered study area in Alaska.

ation Area and a portion of the Steese National Conservation Area; the quantities and values of minerals that may be economically recoverable; and the amounts made inaccessible by the resource management plans. At the request of the BLM district manager, the mineral potential in 11 distinct geographic blocks was also estimated.

Based on Bureau analyses, it is almost certain that three of these blocks contain undiscovered mineral deposits, and there is a good chance (between 35% and 55%) that such deposits remain to be found in three others.

The study found a probability of economically recoverable mineral deposits in each BLM-designated block and identified the block with the greatest favorability for mining activity. The study estimated the potential economic importance of mining activity in each block at current prices and at triple current prices. Three blocks would generate the largest net present values (NPV's) at current prices; four others would generate NPV's in excess of $100 million at the higher price level; the block most likely to experience mineral activity would generate relatively small values because of the type of deposit contained (gold placers).

Minerals availability data base available for personal computer (PC) use. The advanced deposit information tracking (ADIT) system data base, which contains information on mineral occurrences, mines, and mineral processing operations, has been developed in a fast, easy-to-use PC format. ADIT is the public access version of the Minerals Availability System (MAS) data base. The MAS data base contains comprehensive engineering and economic data used to determine the availability of strategic and critical minerals and for other analytic applications.

PC-ADIT contains site-specific information on over 3,000 mineral operations with an emphasis on operations located in the United States and other market economy countries. The data base covers 34 commodities that represent those most significant in terms of value, tonnage, and import reliance. Information contained in PC-ADIT is reviewed and updated every 6 months. PC-ADIT menus guide the user through a criteria selection process in order to sort the data by location, commodity, company, or several other criteria. Help keys explain the criteria, while choice keys provide a list of options within a criteria category. Because the ADIT data base resides within the PC, sorts are relatively fast, usually taking a minute or less. The PC-ADIT software is available for IBM or IBM clone PC's. The software and data base require about 2 megabytes of hard disk memory.

Economic Analysis

Relative competitiveness of U.S. and Canadian coal producers. An analysis of the cost competitiveness of representative coal producers in the United States and Canada has been jointly published by the Bureau and the International Trade Administration of the Department of Commerce. Like the previous U.S.-Colombian study, mine-mouth cost structures at physically similar deposits and operations in each country were estimated to isolate and compare costs associated with environmental, health, and safety regulations, and labor. Transportation costs also were determined and combined with mine-mouth costs for coal mines in the two countries to compare the delivered costs to three common markets.

Two structural cost comparisons indicated that only tax costs differed significantly between the two countries. The revenue- or tonnage-based severance taxes and regulatory taxes (for black lung and abandoned mine land reclamation) on U.S. mines have no Canadian counterparts. These taxes yield U.S. authorities more stable receipts while the income (revenue less expenses) base used for virtually all Canadian taxes splits the burden of fluctuating coal market prices between the coal producers and the Government.

Three delivered cost comparisons isolated the key cost differences among mines selling similar coal to common customers. Large western Canadian surface coal mines have mine costs similar to eastern U.S. mines that serve northeastern U.S. electric powerplants with ocean terminal facilities. The Canadian mines were found able to sell in that market when ocean freight rates were low enough. Utah mines have higher mining costs than western Canadian mines serving California industrial customers but could deliver coal at competitive costs to customers who do not have direct access to ocean shipments. Western Canadian metallurgical coal could be mined substantially cheaper than eastern U.S. coal and shipped to Japan for slightly less than eastern U.S. coal. The superior coking qualities of the U.S. coal offset these cost disadvantages and enables it to compete in the Japanese market.

The Colombian and Canadian comparisons, along with comparisons of Australian and South African mines with U.S. mines under development, were requested by Congress to assist it formulate coal trade and tax policy.

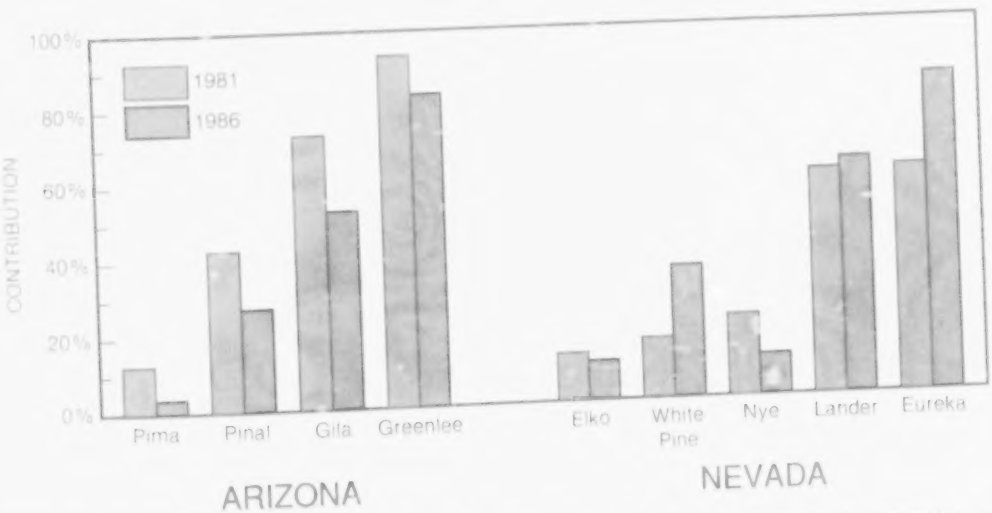
Impacts of a U.S. embargo on South African strategic and critical materials. The Comprehensive Anti-Apartheid Act of 1986 prohibits U.S. imports of products produced, manufac-

mined, marketed, or exported by South African parastatal organizations. Section 501(c) of the act introduces additional measures that could be undertaken by the United States, including the prohibition of strategic and critical material imports from the Republic of South Africa (South Africa). To assist the President and the Congress in determining the national implications of such a prohibition, at the request of the Department of State, Bureau analysts assessed direct costs to this nation resulting from a U.S. embargo on South African strategic and critical minerals.

The minerals or mineral groups produced by (or transported for export through) South Africa that are included in this assessment are platinum, palladium, rhodium, chromium (including ferrochromium), manganese (all forms), vanadium (including ferrovanadium), titanium source materials, including rutile and rutile substitutes (titaniferous slag), and cobalt (which is transported through South Africa).

The study estimated direct economic costs to the United States resulting from a decision to embargo South African strategic and critical minerals imports at $1.85 billion per year during the 1988 through 1992. The estimated direct costs include costs to U.S. consumers resulting from higher strategic mineral prices, lower mineral consumption, and the cost of developing domestic mineral resources. Assuming non-South African supplies that were formerly purchased by countries other than the United States would be made available to the United States at a price, there are sufficient alternative world sources for manganese, chromium, palladium, titanium, and vanadium to meet U.S. industrial demand. Alternative world sources for platinum and rhodium cannot meet U.S. industrial demand.

Regional economic impacts of changes in mineral industry activities. As part of a program to determine the impacts of changes in the nonfuel mineral industries upon regional economies, the Bureau published results of two studies examining the State and local economies of Arizona (OFR 30-88) and Nevada (OFR 23-88). The studies are based on a regional impact analysis system that estimates direct and indirect impacts on employment, earnings, and taxes at State and county levels when significant changes occur in minerals production. Direct impacts reflect changes in mining and processing industry employment, wages, profits, and taxes paid, while indirect impacts measure the additional effects on the businesses and individuals that supply goods and services to the mining and processing industries and to their employees. Both studies show that though the U.S. nonfuel mineral industry became more competitive by cutting costs and becoming smaller during the 1980's, the industry is still important to several rural counties in Arizona and Nevada. The Nevada study also estimated that the gold and silver boom indirectly created 11 jobs in Nevada for every 10 new mining jobs, along with 80 cents of additional earnings for every new dollar earned by mining employees.



Changes in the nonfuel mineral industries can have significant impacts upon regional economies, as is shown by the contributions of direct and indirect earnings from the nonfuel mineral industries to total earnings for counties in Arizona and Nevada. (The nonfuel mineral industry in Arizona includes metal processing.)

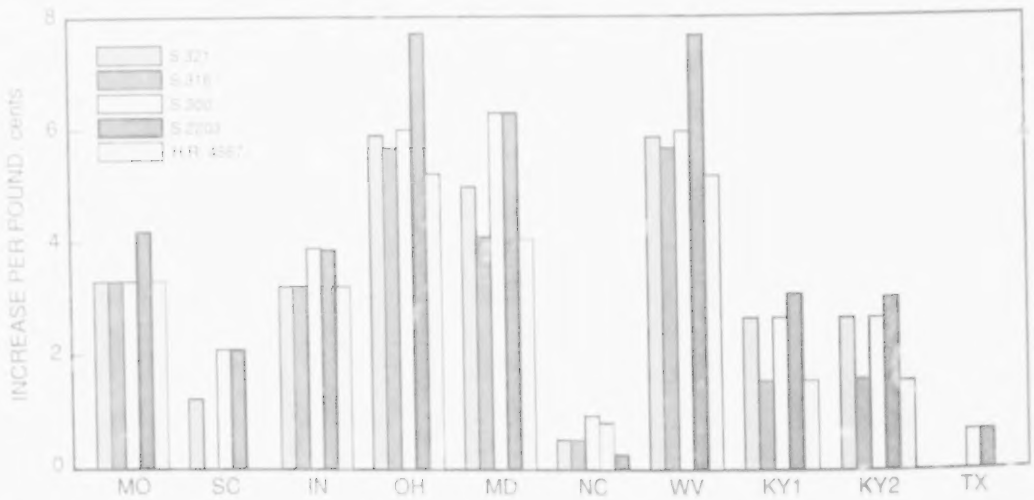
Impact of lending activities by international financial institutions. Assistance from international financial institutions (IFI's) promotes the economic and social development of less developed countries (LDC's), contributing to a more secure and politically stable world. IFI lending may also provide foreign producers with an unfair cost advantage, while promoting increases in worldwide production capacity of minerals already in oversupply.

Recent legislation requires U.S. representatives of IFI's to consider opposing the financing of projects that (1) contribute to worldwide surplus for over half of the economic life of the project or (2) could be financed at reasonable terms by commercial lending services. The U.S. Bureau of Mines assists in the decisionmaking process by evaluating the contribution of each mineral project to surplus capacity in the industry and represents the U.S. Department of the Interior on the Treasury Department working group that reviews proposed IFI loans. The Bureau provided the analyses necessary to evaluate 25 proposed IFI mineral project loans to LDC's in 1988.

Potential impact of acid rain legislation. The Bureau has developed estimates of the economic impact of proposed acid rain legislation on the aluminum smelting industry (OFR 58–88). Aluminum smelting is an energy-intensive industry. In the United States, electricity costs make up about 30% of the cost of producing aluminum. Because of relatively high electricity rates (about 7 mills per kilowatt hour higher than the rest of the world), the United States is a high-cost producer of aluminum relative to most competing world producers (about 5 cents a pound of aluminum higher, on average, than the rest of the world). Approximately 20% of the U.S. aluminum industry has shut down since 1981 as a result of high costs compared to market prices, and no new domestic smelting capacity increases are planned.

The competitive position of about half the industry, which buys power from coal-burning utilities, could be further jeopardized by increases in electrical rates brought on by proposed acid rain legislation. As a result of both industry and congressional concern, the Bureau analyzed the impact of proposed acid rain legislation on the domestic aluminum smelting industry. Estimates were made of the impacts on the costs of production of changed electrical rates for particular aluminum smelters that purchase or use power from coal-based generating plants.

The increases in utility rates that would result from passage of five recently introduced bills were estimated to range from 0 to 10.4 mills per kilowatt hour, depending on the bill and on the particular utility affected. The average increase in electricity rates per bill for 10 aluminum smelters examined was estimated to range from 3.5 to 5.5 mills per kilowatt hour. These rate increases would increase the electricity costs to the U.S. aluminum industry annually from $94 to $150 million. The average cost increase of the 10 smelters—per pound of aluminum—was calculated for each bill, and is estimated to range from 2.5 to 4 cents a pound. Smelters in West Virginia and Ohio would have the highest cost increases, from 5.2 to 7.7 cents a pound.



The Bureau evaluated the impact of proposed acid rain legislation on aluminum production costs of smelters located in Missouri, South Carolina, Indiana, Ohio, Maryland, North Carolina, West Virginia, Kentucky, and Texas.

Other Activities, Reports, and Accomplishments

Bureau participation in international commodity organizations. For several nonfuel mineral commodities, international commodity organizations draw on the expertise of the Bureau's commodity and country specialists. These bodies, such as the International Lead and Zinc Study Group (an autonomous organization) and the Tungsten Committee (part of a United Nations body), provide consultative forums for the Government members on issues related to the commodities. The work of these organizations involves the collection of authoritative information for the commodities as an aid in achieving better market balance for supply and demand. Such organizations have also been proposed for tin, nickel, and copper. Bureau personnel have been intimately involved in preparatory meetings to establish the goals and procedures, policy, data needs, and work program of the proposed new organizations. In 1988 progress was made in negotiating sessions toward the formation of an International Copper Study Group. Data and information published by these organizations are used worldwide by industry and market analysts in making investment and loan decisions, by academia, and by Government policy analysts.

Data reports. Each January the Bureau publishes *Mineral Commodity Summaries*, which reviews events and presents statistics on mineral operations for the previous year. These are the first statistics published by the Bureau that cover the full year just ended, but because of the early publication date, data for the last several months of the year are estimated. This publication presents a two-page summary of salient information on each of approximately 90 mineral commodities. The same format is maintained for each commodity for ease in finding desired information and in making comparisons between commodities.

Monthly and quarterly data are published as *Mineral Industry Surveys*, which cover a single mineral commodity and are published as soon as the data are available, usually 45 working days after the close of the period reported. These reports are eagerly awaited each month by those engaged in mineral sales and purchases, who must keep abreast of the condition of the markets in which they are operating.

Annual data, which are more detailed than the monthly and quarterly data, are published in the *Minerals Yearbook*. Volume I contains a separate chapter on each of the minerals reported. Statistics, both domestic and foreign, are presented along with an analysis of important events affecting the industry that year. The standardized subheadings within each chapter are Domestic Production, Consumption, Stocks, Prices, Foreign Trade, World Review, and Technology. In addition to the chapters on individual commodities, volume I includes a "Mining and Quarrying Trends" chapter. That chapter contains statistics on the number and sizes of mines, quantity of ore and waste handled, grade of ore treated, and exploration and development work done. Volume I is published in December following the reported year.

Volume II of the *Minerals Yearbook* contains chapters on the nonfuel mineral industry of each of the 50 States, the U.S. island possessions in the Pacific Ocean and the Caribbean Sea, and the Commonwealth of Puerto Rico. Volume III contains a separate chapter on each mineral-producing country of the world. The mineral production and trade statistics of the country are reported, along with an analysis of significant events affecting the minerals industry of the country in the year being reported. Volume III is published approximately 15 months after the year being reported.

The *Minerals Yearbook* is the definitive historical record of worldwide mineral activity, and is relied upon for that record by a worldwide clientele. Its reporting of annual statistics and major mineral-related events serves as a basis for measuring historical trends and for making longer term projections. Its clientele are those involved in formulating minerals policy in National and State Governments and those involved in making development decisions in the minerals industry.

International series publications. The Bureau produces and periodically updates six reports that cover the minerals industry of the world. Each report covers one area of the world such as Latin America or Africa. Each country of the area is discussed in a standardized format, which includes a country map showing the locations of mineral deposits and of mineral processing facilities, followed by a table with statistics on production, reserves, and trade.

An update for Latin America was published in 1988, and an update for the Far East and South Asia will be published in 1989. In draft are reports on the mineral industry of Guinea, the iron and steel industry of China, and the mineral industry of Mexico.

In the Mineral Issues series, a report on the tungsten industry of the U.S.S.R. was completed, and a report on the nickel-cobalt industry of the U.S.S.R. is in preparation.

Helium Activities

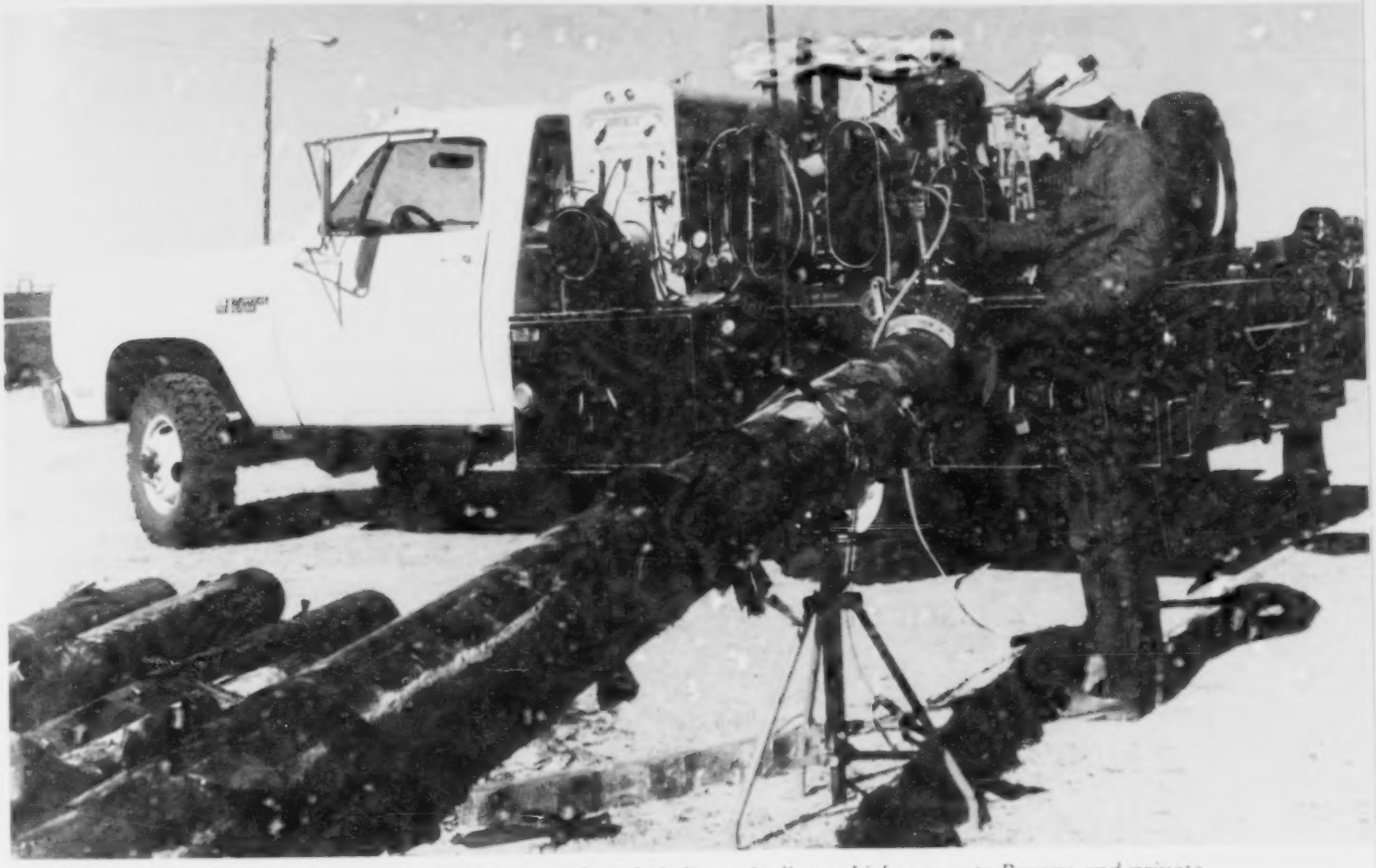
The Federal Helium Program, as conducted by the Bureau of Mines under the Helium Act Amendments of 1960 (Public Law 86-777), provides helium for the current and foreseeable needs of essential Government activities, and fosters individual enterprise in the production and distribution of helium.

Facilities for carrying out the program include a helium processing plant, gaseous and liquid helium shipping facilities, and a helium tank car maintenance shop at the Exell Helium Plant, Masterson, TX; an analytical services laboratory and a highway semitrailer and small cylinder gaseous helium filling facility at the Amarillo, TX, plant; the Cliffside Helium Storage Reservoir near Amarillo; 525 miles of high-pressure helium and natural gas pipelines in Texas, Oklahoma, and Kansas; a pipeline maintenance station at Satanta, KS; and Helium Field Operations headquarters, at Amarillo, TX.

This year, 320 million cubic feet (MMcf) of helium was withdrawn from the Cliffside Reservoir, purified, and distributed to Federal agencies to support such programs as National Aeronautics and Space Administration (NASA) space missions, Department of Defense advanced weapons research and development, and Department of Energy next-generation energy-conversion research and development. Federal helium sales this year include 245 MMcf of gaseous helium and 75 MMcf of liquid helium. The Bureau previously separated all of this helium from natural gas and stored it in the Cliffside Reservoir to provide for current and future Federal helium demand.

All orders for helium by Federal agencies are shipped within 24 hours of receipt. Distribution of Bureau helium to the Federal market requires large numbers of Government-owned shipping containers including high-pressure cylinders,

The Bureau supplies Federal agency helium users with small volumes of liquid helium in dewars filled at its Exell Helium Plant.



The Bureau operates and maintains about 425 miles of crude helium pipeline, which connects Bureau and private helium plants to the Government owned Cliffside Helium Storage Reservoir.

automotive semitrailers, and railway tank cars for gaseous helium; and low-pressure liquid helium dewars and bulk liquid helium semitrailers. Because these containers are used in interstate commerce, they must be maintained and tested in accordance with Department of Transportation regulations. Tank car maintenance and hydrostatic testing are done at the Exell Helium Plant. High-pressure cylinders are maintained and hydrostatically tested at the Amarillo Helium Plant, while the maintenance of gaseous semitrailers and dewars is done at both the Amarillo and Exell Helium Plants.

The Bureau's program for storage of private crude helium in the Cliffside Field near Amarillo, TX, is indispensable for the private helium industry. Over 70% of the private helium market has been supplied from this source during times of short supply. Private crude helium is stored under contract with the Bureau when supply exceeds demand, usually during winter heating season. During shortage periods, helium is returned to owners for purification and sale in the private helium market. In summer, crude helium is in short supply because of the reduced summer demand for natural gas, which contains helium, and the diminishing supply of higher helium content natural gas. Current low prices and reduced demand for natural gas and natural gas liquids have not been conducive to increasing helium supplies. The shortage can be expected to continue at least until the beginning of the fall heating season. Without the Bureau's countercyclical storage program for private helium, private industry would find it difficult to supply the current private demand.

The Bureau makes helium available to university and college facilities in support of vital federally funded research. These small users can obtain helium directly from the Bureau, or from private helium distributors who establish and maintain their eligibility to distribute Bureau helium. In these ways, smaller helium users have access to a reliable helium supply when it is needed. Price, service, and container availability make the purchase of Bureau helium attractive to many researchers.

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Mineral Institutes

Under this program the Bureau of Mines makes grants to 32 research oriented colleges and universities having substantial graduate programs of instruction and research in the mineral sciences and engineering. These institutions have been designated as State Mining and Mineral Resources Research Institutes. The Mineral Institutes program is authorized under Public Law 98-409, the State Mining and Mineral Resources Research Institute Program Act, and was extended through fiscal year 1994 by the passage this year of Public Law 100-483.

To maximize their effectiveness, research funds have been concentrated in certain broad mineral engineering research areas located at a single institution (with several participating affiliates). In 1982, generic mineral technology centers were set up for: mine systems design and ground control (Virginia Polytechnic Institute and State University); pyrometallurgy (University of Missouri-Rolla); comminution (University of Utah); and mineral industry waste treatment and recovery (University of Nevada-Reno). In 1983, a fifth generic mineral technology center for respirable dust research was established jointly at Pennsylvania State and West Virginia Universities. Three of these generic centers are located near Bureau research facilities (Rolla, MO; Salt Lake City, UT; Reno, NV) that are either on or adjacent to the university campuses. This proximity is conducive to exchange of equipment, ideas, and personnel. This year a sixth generic center in marine minerals technology was added at the University of Mississippi (in cooperation with the University of Hawaii).

Each generic center holds an annual seminar where students and faculty present their ongoing research for discussion and for the information and stimulation of peers. Each generic center has a research advisory council of scientific experts in that generic area from industry, academia, and Government. Council members are apprised of progress of the generic center through periodic reports and attendance at the annual seminar. The research advisory councils provide recommendations on the direction of each generic center to the center director and the Bureau. Each center also maintains a reference center that serves as a clearinghouse for technical information for the generic area and supplies reports on generic center accomplishments.

Mineral institutes are located at the following institutions of higher learning:

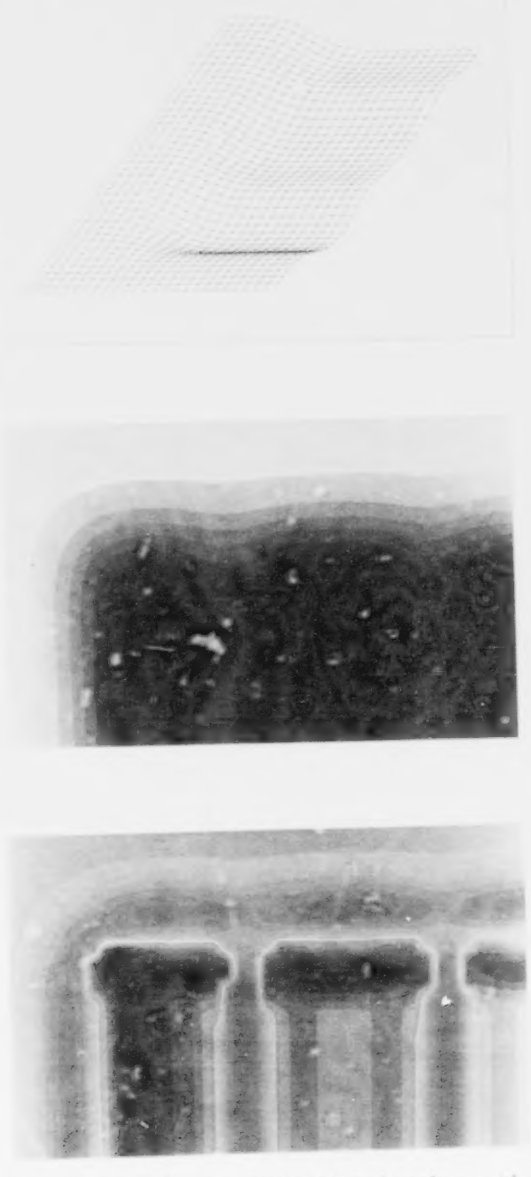
University of Alabama[1]
University of Alaska-Fairbanks[1]
University of Arizona[2]
University of California-Berkeley[3]
Colorado School of Mines[1,4]
Georgia Institute of Technology
University of Idaho[1]
Southern Illinois University[1]
Purdue University[4]
Iowa State University
University of Kentucky[1,4]
Louisiana State University
Massachusetts Institute of Technology[4,5]
Michigan Technological University[3,5]
University of Minnesota[2,5]
University of Mississippi[6]
University of Missouri-Rolla[4]
Montana College of Mineral Science and Technology[2]
University of Nevada, Reno[1,2]
New Mexico Institute of Mining and Technology
Columbia University[4]
University of North Dakota
Ohio State University[4]
University of Oklahoma[2]
Pennsylvania State University[2,3,5]
South Dakota School of Mines
University of Texas[1]
University of Utah[1,3,4]
Virginia Polytechnic Institute and State University[1,3]
University of Washington
West Virginia University[5]
University of Wyoming

[1] Affiliated with mine systems design and ground control generic center.
[2] Affiliated with mineral industry waste treatment and recovery generic center.
[3] Affiliated with comminution generic center.
[4] Affiliated with pyrometallurgy generic center.
[5] Affiliated with respirable dust generic center.
[6] Affiliated with marine minerals generic center.

Generic Mineral Technology Center for Mine Systems Design and Ground Control. An analysis of caving and mass deformation characteristics above longwall and room-and-pillar mines in Appalachia was completed. Particular emphasis was placed on the effects of the geological and geomechanical characteristics on the two most important manifestations of roof caving, the caving height and the bulking of the caved material. The former determines the weight of the strata that the supports are called upon to accept and the latter defines the expansion ability of the broken material. A mathematical model has been developed, based on the finite element method. This model incorporates concepts related to the mechanics of strata deformation and empirical indexes associated with subsidence engineering. Deformation zones based on empirical parameters have been defined in overburden in an attempt to simulate theoretical and observed strata deformation characteristics. Accurate subsidence and horizontal strain calculations have verified the modeling procedure with respect to the strata deformation zones.

An evaluation was made of the significance of subsidence, curvature, and horizontal strains on the response of surface structures, and the underground precautionary measures that can be taken to minimize and control such damage. The study demonstrated that the mining geometry and configuration of panels, as well as extraction sequence, can have a substantial impact on the surface ground movement. As opposed to fixed mine design parameters (e.g., depth or mining height) the parameters cited previously are variable design parameters and thus can be planned accordingly. As a result, surface subsidence characteristics and their potential impact upon surface structures should always be considered in order to determine the optimum design of mine panels.

An extensive study of damage criteria and precautionary measures recommended in other countries was completed to evaluate their applicability to U.S. mining and geological conditions. Consideration has been given to both factors contributing to structural damages: The ground movement components and the characteristics of a specific structure. The continuous advance of the faceline during mining causes a dynamic propagation of surface displacements. The dynamic effects often promote a different reaction by surface structures than that due to static movements. This research also addresssed the time factor of subsidence and the development of both the static and dynamic deformation profiles in assessing damage to structures.



Typical computer output of predicted surface settlements and corresponding subsidence and strain color contours for a series of longwall panels.

Ground movement prediction techniques, developed by Virginia Polytechnic Institute and State University during the past few years, are currently being evaluated and tested for developing appropriate guidelines and subsidence engineering principles when undermining surface structures.

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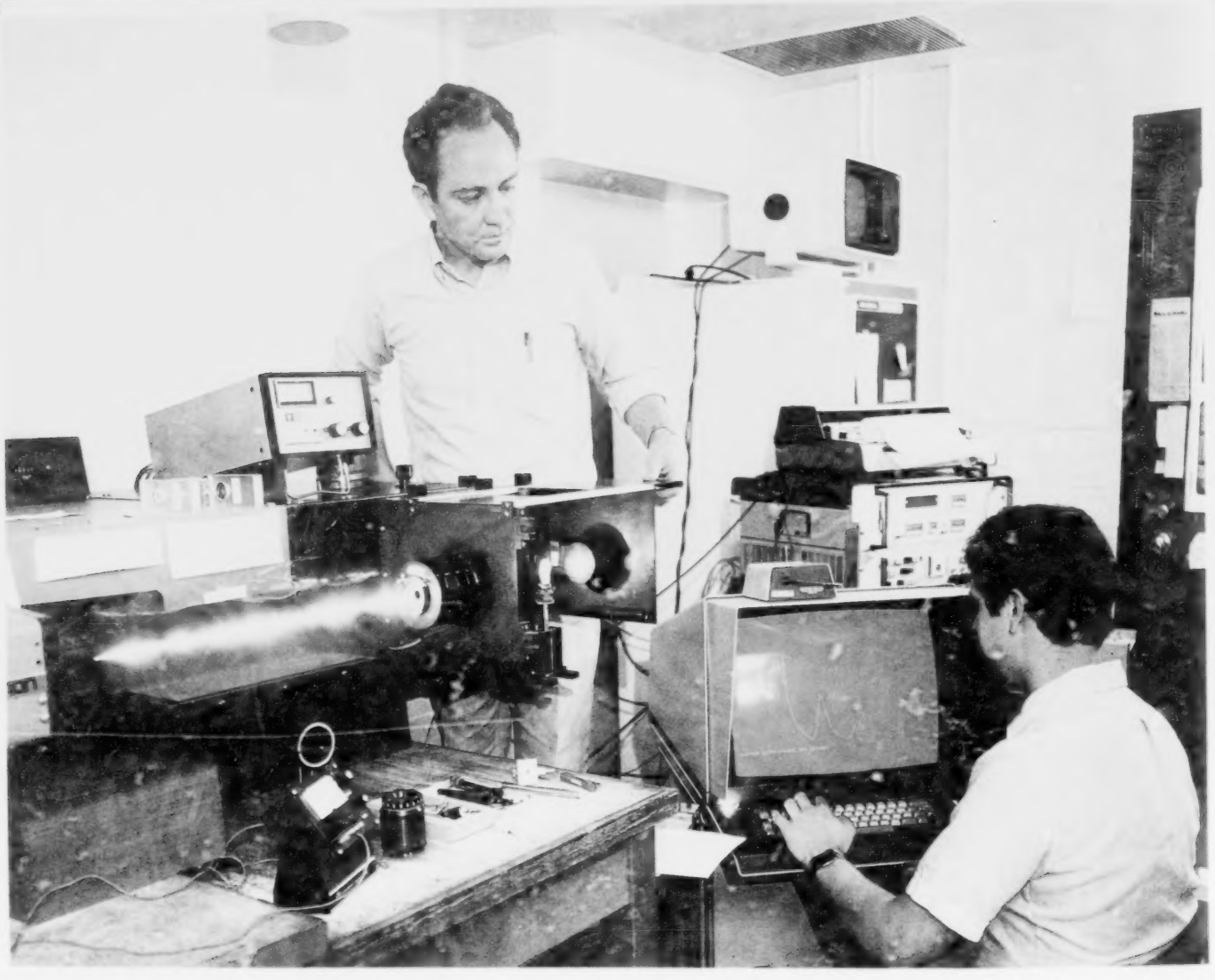


A laser Raman spectrophotometer is used to analyze the amount of diesel particulate on filters collected in a coal mine in which diesel equipment was used.

Generic Mineral Technology Center for Respirable Dust. Research in the respirable dust center on diesel equipment in underground coal mines is primarily in the areas of distribution and characterization of diesel exhaust particulates in mine atmospheres; assessment of genotoxic potential of diesel exhaust and mine dust atmospheres; evaluation of effects of engine operational conditions and exhaust control methods on emission quality; and safety, productivity, and economic aspects of diesel-powered equipment deployment.

A project at Michigan Technological University is directed toward developing improved methods to measure concentrations of diesel exhaust in underground coal mines. There is no fully proven quantitative measurement method to differentiate between diesel and coal particles in samples of airborne respirable dust from coal mines that employ diesel-powered equipment. Pollutant concentrations must first be accurately measured to further engineering control of airborne diesel exhaust particulate and gaseous components.

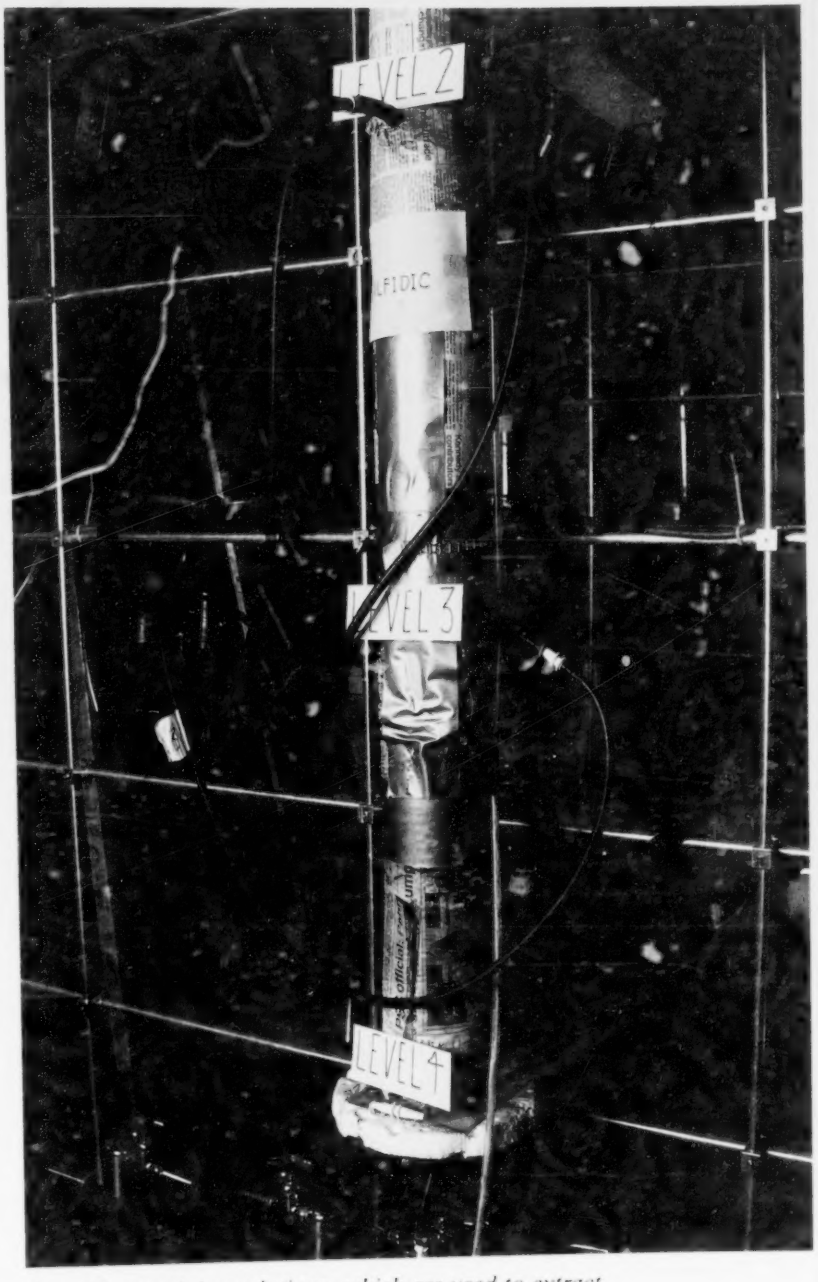
The research has emphasized the development of the laser Raman quantitative analysis (LRQA) method. An important feature of this method is the use of particulate samples that are collected by gravimetric personal samplers as used by the mining industry and Mine Safety

and Health Administration to determine the airborne respirable coal dust concentrations. While the initial verification of the method was made through laboratory generator samples, the LRQA method is being verified using airborne dust samples collected in an underground coal mine. The analyses to date indicate that going from laboratory to mine samples requires refinement of both sampling and LRQA procedures to maximize precision and accuracy.

The LRQA method results are being compared with those from the size-selective sampling method being developed by the Bureau of Mines and the University of Minnesota. For these purposes, airborne respirable diesel-coal particulate mixtures for the LRQA and size-selective methods are collected simultaneously and side by side. The preliminary results at two locations in an underground coal mine using diesel equipment reveal reasonable agreement between the methods.

Refinement of the LRQA method, additional underground sample collection activities, and evaluation of exhaust emission control equipment are being addressed in continuing projects in the respirable dust center.

Generic Mineral Technology Center for Mineral Industry Waste Treatment and Recovery. Sodium cyanide solutions were percolated through opaque columns filled with three ore types (sulfidic, oxidized, and carbonaceous) and the effluent was analyzed as a function of column position and time for the concentrations of weak acid dissociable (WAD) and total cyanide, ferricyanide, ferrocyanide, and thiocyanate cuprocyanide. Extended percolation time led to increases in WAD cyanide concentrations and decreased thiocyanate and cuprocyanide concentrations, regardless of ore depth. WAD cyanide concentration decreased while ferrocyanide concentration increased with ore depth. Highest concentrations of ferrocyanide, thiocyanate, and cuprocyanide were found in the sulfidic ore, with expected low WAD concentrations. Lowest concentrations of ferrocyanide, thiocyanate, and cuprocyanide were found in the oxidized ore. These data are pertinent to the nature of cyanide species found in precious metals mill tailings impoundments.



Cyanide-containing solutions, which are used to extract valuable components from ore, are gradually detoxified by reaction with other elements in the ore or surrounding soil such as sulfur, iron, and oxygen. These reactions may be catalyzed by sunlight and other components naturally present. A column is used at the Mineral Industry Waste Treatment and Recovery generic center to evaluate the time dependence of natural cyanide detoxification and the ultimate fate of the cyanide.

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Process Evaluation

The role of the Process Evaluation staff in the Bureau is twofold. Its primary function is to provide economic and technical assessments for guiding research programs, with a secondary function of aiding technology transfer to industry. Through economic and technical studies assessments, management is provided another means for assessing the potential value of the research venture; the researcher is provided with a basis for selecting various research possibilities to address potential high-cost areas; and industry is provided with the economic commercial value of Bureau-developed processes and mining systems.

Process evaluation is most useful when first performed in the early stages of research. Raw data from laboratory and bench-scale research are extrapolated to provide a basis for designing industrial-scale operations. Next, preliminary capital and operating costs for each operation are estimated. From this information specific steps in the operations can be targeted for additional research, and plans can be modified to examine these areas in greater detail. After additional research is conducted, additional process evaluations are performed to provide further guidance. With repeated interaction and feedback between research personnel and Process Evaluation personnel, the Bureau's research is focused on areas critical to development of economically and technically feasible processes.

The Process Evaluation staff examines the research from a varied and detached perspective. Each technology under investigation is projected from a laboratory scale to a commercial-plant scale. Problems and their solutions become more apparent from this perspective. In addition, the Process Evaluation staff is familiar with a broad range of technologies spanning the minerals industry; therefore, modifications or alternative technologies that otherwise might be missed can be suggested.

Various types of information that are vital in developing economically viable solutions to mineral problems are presented in each evaluation. By examining individual processing steps, the high-cost ones are identified. These can then be investigated by research personnel to determine process modifications to reduce the cost of these steps. Process evaluation studies also identify and rank in importance areas in which additional research data are needed, both from a technical and a cost standpoint. In addition, performing process evaluations allows process variations to be compared and their relative worth assessed. Both similar and dissimilar operations can be contrasted using cost as a common denominator.

Process costs are the primary means of comparing competitive technologies. Therefore, the availability of this information makes the research accomplishments more useful to industry and speeds their adoption. To aid technology transfer to industry, economic evaluations are published independently or included in publications describing the research.

Although not part of the regular evaluation work, a major effort during the year has been directed toward the design of conceptual processes for treating two Superfund sites. In the first, technology developed for recycling discarded batteries was adapted to treat soil at the United Scrap Lead Superfund Site. Although almost no laboratory data were available for treating the soil, it was possible to develop a flowsheet and preliminary cost estimate for this material. Using the proposed flowsheet, data needs were developed so that it would be possible to design a pilot plant with a minimum of laboratory research. For the second site, process evaluation was used to identify the most promising area of research from those that had been proposed using Bureau of Mines expertise for treating an old tannery waste pit.

Regulatory Projects Coordination

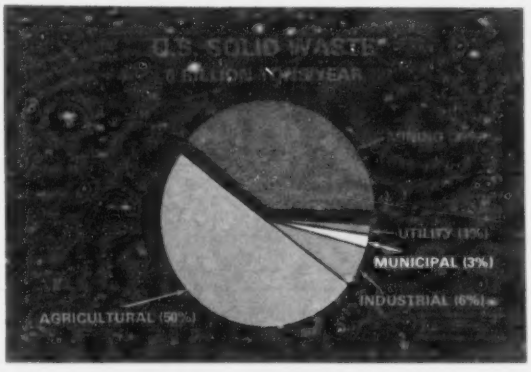
The Office of Regulatory Projects Coordination was established in 1986 to enable the Bureau to become proactive with respect to rulemaking and regulations that could have and do have significant impact on the minerals sector of the economy. Heretofore, the Bureau has been relatively unobtrusive in its approach toward mining and minerals regulatory issues. In part, this was the direct result of the transfer of the Bureau's previous regulatory function (Mining Enforcement and Safety Administration) to the Department of the Interior in 1973. The transfer of this regulatory function was undertaken to avoid any apparent conflict of interest on the part of the Bureau, principally with respect to coal mining productivity.

From 1973 to the mid-1980's, the Bureau intermittently became involved peripherally on

some mineral-related regulatory issues. Among the most notable of these was the creation of particulate mineralogy unit (PMU) in 1976. The PMU was formed to bring precision, conformity, and scientific knowledge into what had become unreasoned debate in the literature and popular press concerning asbestos and asbestiform minerals and their related health effects. The PMU provided assistance to local, State, and Federal agencies in establishing precise and workable mineral definitions, methods of mineral particulate identification, and quantitative measurement.

During this same time period, the mining and minerals processing industries absorbed the impact of several very significant environmental and worker health and safety regulations. However, industrial solid waste remained largely unregulated, at least at the Federal level. But, by the mid-1980's, court decisions increased the Environmental Protection Agency's (EPA) level of activity in regulating mining and mineral processing wastes. Recognizing the tremendous magnitude of the impact that the regulation of mining and mineral processing wastes could bring to the domestic minerals industry, the Bureau consciously adopted a more proactive role in regulatory development.

The Office serves as a focal point within the Bureau, identifying, monitoring, and assessing both current and evolving regulatory issues, and external to the Bureau, interacting with offices and bureaus of the Department of the Interior, other Federal and State agencies, the Congress, as well as private organizations and interest groups. As the focal point, it is able to marshal all the Bureau's talents and capabilities on regulatory matters, crossing organizational interests and lines. Of particular concern are regulations and rules promulgated by EPA; the Mine Safety and Health Administration; the Occupational Safety and Health Administration; the Office of Surface Mining, Reclamation and Enforcement; and the Minerals Management Service. As a consequence, the scope of the Office's activities is very broad.



Mining and mineral processing generate about 40% of the Nation's solid waste.

Today the Office's primary interest remains the regulation of mining and mineral processing solid wastes. Two major legislations, the Resources Conservation and Recovery Act of 1976 (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), provide for the management and control of hazardous and nonhazardous wastes and for the cleanup of releases and potential releases from nonactive operations. Because the mining and mineral processing industries generate millions of tons of waste materials each year, they are subject to regulation under RCRA and CERCLA as well as other equally onerous requirements that are designed to protect both human health and the environment. While the issues are extremely complex and various advocacies are championing their respective positions, the Bureau has entered into the deliberations and regulatory-determining process by bringing its longstanding mining and minerals technical expertise to the attention of the regulators. As a consequence, the Office has become an highly respected and persuasive influence that remains objective, keeping the Nation's vital mineral needs of paramount concern.

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Organizational Data

The overall mission of the U.S. Bureau of Mines is to help ensure that the United States has an adequate and dependable supply of minerals to meet its defense and economic needs at acceptable social, environmental, energy, and economic costs.

The Bureau is headquartered in Washington, DC, with field facilities and associated supporting offices located throughout the United States. The Bureau is headed by a Director and Deputy Director.

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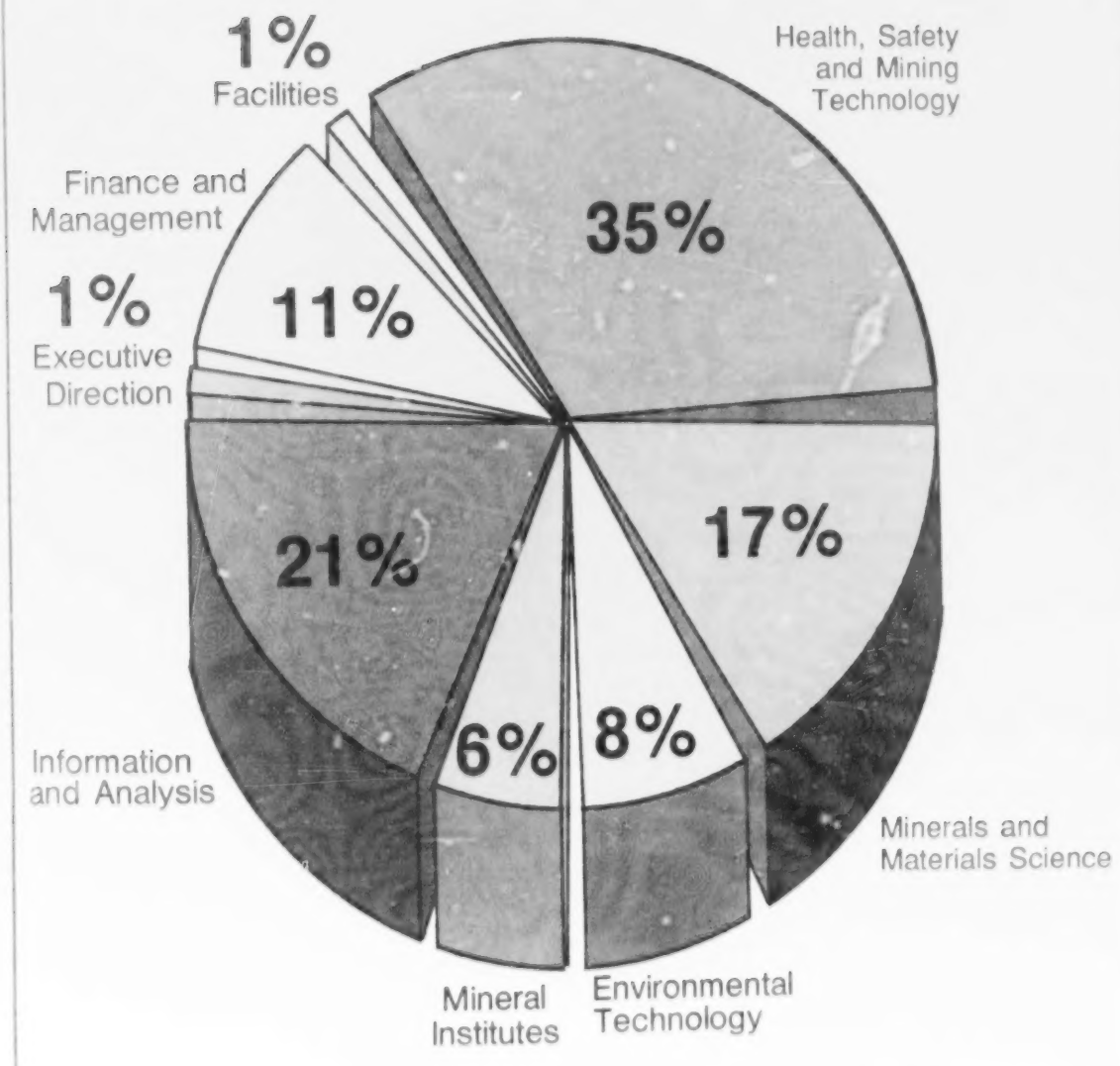

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RECENT PUBLICATIONS AND PATENTS

Results of Bureau investigations are published as Reports of Investigations (RI's), Information Circulars (IC's), and Bulletins. Many of these publications are available at no cost and can be obtained by writing—

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